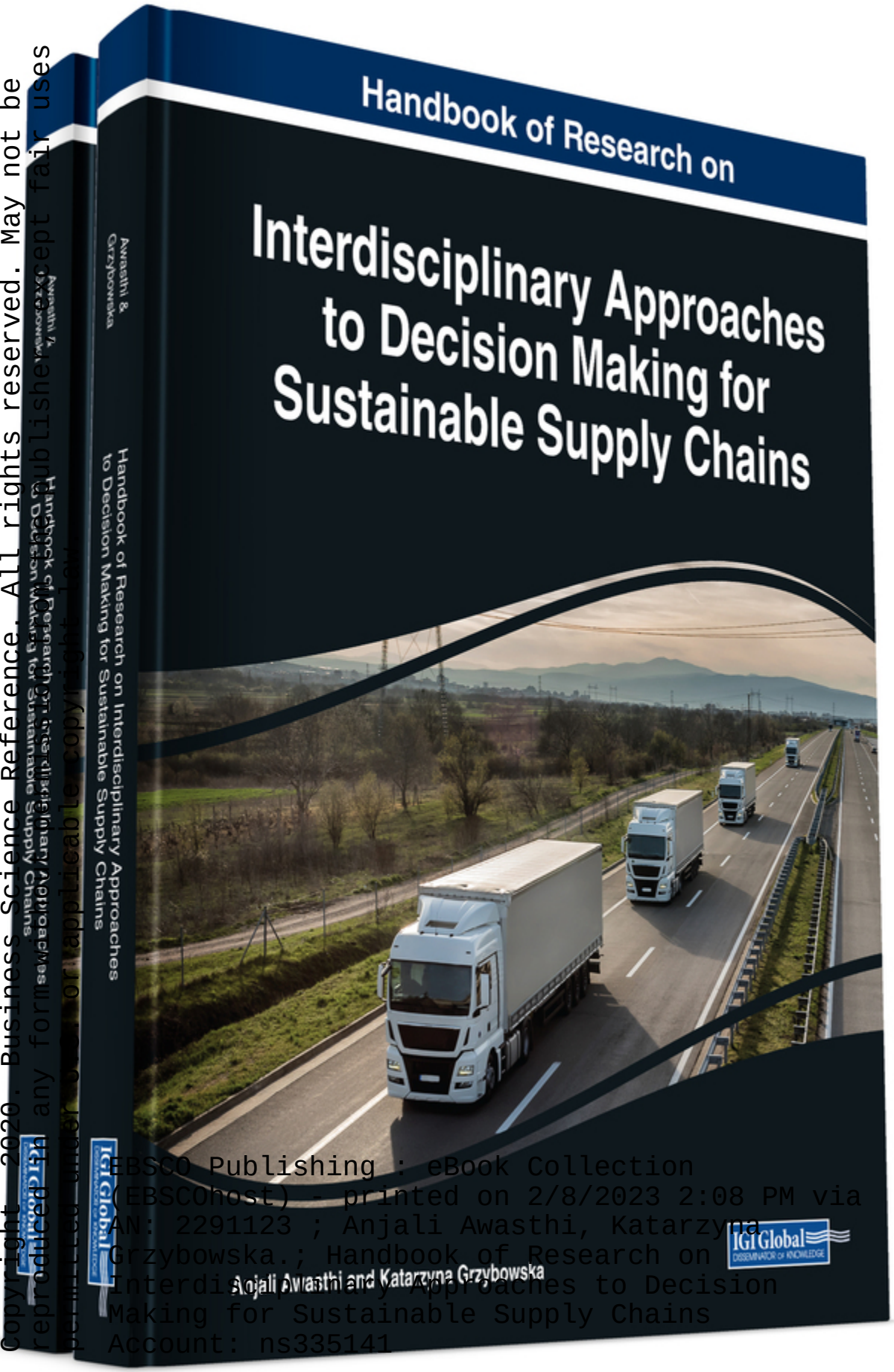

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Handbook of Research on Interdisciplinary Approaches to Decision Making for Sustainable Supply Chains

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A volume in the Advances in Logistics, Operations, and Management Science (ALOMS) Book Series

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Supplier selection is critical for sustainability management in global supply chains. In this chapter, the authors present a content analysis based literature review for global sustainable supplier selection. The supplier selection is investigated along four dimensions, namely economic, environmental, social, and global. The results of the study yield that environmental and social criteria are often used together for supplier selection whereas global risk criteria are rarely used, even less as we move along multiple tiers of the supply chain. From the review, the authors also identified the top criteria along these four dimensions for global sustainable supplier selection. Along the economic dimension, the top three criteria are quality, cost, and general supplier characteristics. The social dimension has employees, transparency and engagement, and local communities' influence as the top criteria. Along the environmental dimension, the top criteria are pollution and hazardous emissions, standards and management systems, green product and design, and green competencies and processes. The top criteria along the global dimension are distance, other risks, and politics and economy.

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Morteza Yazdani, Universidad Loyola Andalucia, Spain
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Sustainability in industrial organizations has become a predominant concept in the 21st century due to environmental regulations, economic importance, and social obligations. In this context, sustainable supplier selection plays an epochal role for taking strategic business decisions. So, a systematic approach is required to deal with the sustainable factors. By integrating the three pillars of sustainability, namely economic, environmental, and social factors, this chapter presents an integrated model for supplier

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selection from a sustainability perspective. The proposed framework combines analytic hierarchy process (AHP) and quality function deployment (QFD) methods to deal with the sustainable criteria. Finally, suppliers are ranked using VIse Kriterijumska Optimizacija kompromisno Resenja (VIKOR) method. The proposed framework is used to analyze a case study of a dairy company, but it can also be implemented for sustainable supplier selection in any industries. The study brings an artefact for managers to effectively analyze suppliers with the integrated decision-making model.

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Benchmarking Sustainability Performance of Suppliers Using ISO 14001 and Rough Set QFD-Based Approach 55
Ramneet Sidhu, Concordia University, Canada
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Supply chain management plays an important role in design, development, manufacturing, etc. and has key impact on company's overall environmental performance. Recently, green supply chain management has gained great interest from researchers and practitioners. Consideration has been given to consider environmental factors in entire supply chain starting from procurement, production, transportation, consumption, and post-disposal of products to make the whole product life cycle green. And those companies implementing ISO 14001 are controlling and minimizing risks not only internally but also externally with their suppliers. In this chapter, the authors are benchmarking sustainability performance of suppliers using ISO 14001 and rough set QFD. For this objective, firstly they identify the requirements for green supply chain planning on the basis of ISO 14001. Then, they evaluate the suppliers on the basis of these requirements using a QFD-based approach. To handle the uncertainties arising due to lack of or limited data, rough set theory is used. The results show that the proposed approach can effectively handle imprecise information and facilitates selection of green supply chain initiatives in a structured way.

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Christina Paraskevopoulou, Aristotle University of Thessaloniki, Greece
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The environmental issues and the projected world population increase have brought into light many different terms and concepts. For over 20 years, sustainability attracts the main focus of most researchers; however, recently the concept of circular economy (CE) is considered to be its successor. CE is based on a closed loop supply chain, where waste is minimized and reintroduced into the supply chain, thus requiring a systemic change. In the agri-food sector, the CE principles have many possible applications. This chapter provides a CE perspective for the dairy supply chain by identifying and analyzing the associated technologies and strategies through a literature review taxonomy based on the related stage of the supply chain.

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Abbas Tavassoli, Concordia University, Canada

In this chapter, the authors propose a multi-criteria framework for benchmarking sustainability performance of organizations. The indicators for evaluation are obtained using sustainalytics database. Multicriteria decision making technique called TOPSIS (Technique for Ordered Preference by Similarity to Ideal Solution) is used to generate organization rankings. The proposed technique is applied to evaluate

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performance of 24 companies in two major sectors: manufacturing and service. The selected companies come from the Canadian market. The results of TOPSIS study show manufacturing sector to be doing better than the service sector with average relative closeness (Ci) of 0.5 and 0.36, respectively. Future work can involve integration of financial KPIs, cross-sector investigation and involvement of MCDM techniques such as AHP for weighting in the proposed study.

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Jesus Gonzales-Feliu, Mines Saint-Etienne, France
Gilles Goncalves, Université d'Artois, France

The purpose of this chapter is to study the benefits of collaboration among shippers in less than truckload transportation and to show the role of transhipments in the collaboration. In this chapter, the authors propose a new model for the pickup and delivery problem with transhipment and time windows to study the role of transhipment in the green collaborative transportation. A transportation network with two transportation modes road and sea is considered. Different scenarios are optimized and compared in terms of cost and CO2 emissions: with/without collaboration and with/without transhipment. The proposed model is applied to a case study with real data from three agri-food companies in short sea shipping context. With this model, the total cost and the total amount of CO2 emissions are reduced by using collaboration and transhipment. An experimental study was conducted to illustrate this positive impact.

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Varun Arora, Concordia University, Canada

Sustainability is about meeting the needs of today without compromising the needs of future generations. It involves focus on three main dimensions, economic, environmental, and social, for achieving overall performance. Majority of the companies are adopting sustainability for business growth and boosting their corporate image for long term competitiveness, thereby receiving financial benefits as well. Sustainability is a concept that has come into picture a few years back and presently making a big mark in every field. A balanced scorecard framework is proposed for measuring sustainability performance of business organizations. Four main dimensions are considered, namely organization, process, core, and learning. Each of these dimensions comprises of various indicators obtained from global reporting initiative (GRI) and corporate social responsibility reports. The application of the sustainability scorecard is performed via multi criteria decision making technique called analytical network process (ANP). A numerical study is provided.

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Green procurement, a significant part of green supply chain management, plays a key role in implementing the green concept by considering the environmental issues. Due to increase in public awareness about environmental criteria, industries have been forced to consider environmental issues in their current production flows. Further, since the automotive industry has a direct impact on the environment, it is very beneficial to study the barriers that prevent this industry from implementing the green concept. Iran has had a considerable growth in the automotive industry in the last few decades and today owns and operates the largest automotive factory in the Middle East. In contrast, Canada as a leader in environmental issues does not have a large automotive industry, but is a country where some localized international companies have located small factories. The differences between these two countries make their comparison more valuable and noteworthy. This study investigates this comparison based on a structural modeling methodology known as interpretive structural modeling (ISM).

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Antonio Marcio Ferreira Crespo, Concordia University, Canada
Chun Wang, Concordia University, Canada

The European Union Emissions Trading Scheme (EU-ETS), launched in 2005, is one of the most important market-driven initiatives in support to the global commitment to fight the climate changes and foster sustainable development. The scheme design evolution, comprising four phases, was characterized by continued ineffectiveness in driving emissions reduction, mainly for industries outside the power generation sector. This chapter brings an analysis of the EU-ETS design evolution, aiming at providing an overview on how the EU-ETS design features improvements impacted its effectiveness. The emissions trading scheme's main design features are listed, followed by the description of the EU-ETS design evolution in terms of scope, allowances allocation process, and emissions cap (among others). The greenhouse gases emissions trends, the carbon price behavior, and the availability of allowances in the EU carbon market are presented and discussed as key factors in support to the EU-ETS effectiveness assessment.

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Grzegorz Sierpiński, Silesian University of Technology, Poland
Katarzyna Turoń, Silesian University of Technology, Poland

The recently observed increase in the number of car-sharing operators using a fleet of electric vehicles created an opportunity to expand existing ecological travel chains. Electromobility is one of travelling options that reduces the transport carbon footprint. The goal of the chapter is to draw attention to the need of using car-sharing to promote environmentally friendly behavior and overcome concerns related to using an electric vehicle. The work presents the development of electric car-sharing in Europe and indicates challenges for further expansion of electromobility. By adding electric-car-sharing to the travel chain, the perception of ecological travelling significantly changes, since it combines various advantages for the user (e.g., comfort of travelling and individual trip) and a positive effect of such a choice on the environment and the city.

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Managing Cost of Quality in Supply Chains: Arctic North Inc., Montreal Case Study 231
Ali Ghandour, Concordia University, Canada

The purpose of this case study is to analyze the cost of quality (COQ) in the supply chain process at Arctic North Inc., one of the winter jackets manufacturers in Montreal, Canada. In addition to the case study, some proposed solutions and recommendations will be chosen based on the studied performance of the company. Over the past decades, quality is becoming more and more a key factor in customers' expectations. Organizations and businesses around the world are very interested in applying methodologies and techniques to reach higher quality levels since this will distinguish them from other competitors in the market. Furthermore, measuring the COQ in an organization is very important in order to be able to identify the problem of poor quality, quantify it, and analyze its causes to be able to solve it.

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Ramanpreet Kaur Sapra, Concordia University, Canada

Food packaging is a crucial part of our current lifestyle. It is important to improve the quality of food packaging from time to time, catering to the needs of modern consumers. Despite huge technical advancements, the food packaging sector is still facing several problems and challenges which need to be addressed, to facilitate better packaging. The purpose of this chapter is to enhance the quality of food packaging and to come up with more innovative ideas and methods based on various tools of quality. Various approaches based on new (N7) and basic (B7) tools of quality namely cause and effect diagram, inter-relationship diagram, and affinity diagram have been applied to understand and eliminate the root causes of the various problems being faced by the key supply chain players in the food packaging industry. The results of the study show that the problem does not lie in the methods or techniques applied but in perspective and inclination of the management and key players of the food packaging supply chain towards the quality.

Chapter 13
Using Six Sigma to Achieve Sustainable Manufacturing 266
Min Zhang, Concordia University, Canada

Sustainability has been widely discussed from different points of view. Manufacturing is contributing a critical part of noncompliance to environment and human rights in the modern society. While a lot of companies are seeking strategies to either promote corporation image or stimulate employees' work passion, most of research and guidelines are focusing on how to measure the sustainability based on the cases from big firms. Most of manufacturing firms are medium and small sized; they are searching for a comprehensive and systematical way to implement sustainability practice step by step without using very experienced professionals. This chapter is supplying a systematic framework for firms to achieve sustainability in manufacturing environment with the widely used problem solving tool Six Sigma. Inexperienced professionals will be able to implement the sustainability practice from defining problems to achieving leadership in sustainability. It illustrates how to customize the framework content based on individual needs.

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Chapter 14
A Hybrid Approach Based on SERVQUAL, SERVPERF, and IPA for Measuring Transit Service Quality: With Application for STM, Montreal 295
Mohamad Haidar, Concordia University, Canada

The purpose of this chapter is to discuss the public perception of the quality of service in the public transit system in Montreal using a combination of analyses and surveys. The results are used to make recommendations to improve the STM and its perception. General guidelines of SERVQUAL with some additional questions that are more specific to the current social environment of the city are presented. A survey was conducted by asking 250 international graduate Concordia students to rate a series of statements based on the importance of the issue and how much they agreed with the statement, the results were analyzed using three methods: SERVQUAL, SERVPERF, and IPA. The improvement of timetable synchronization between different metro lines and buses is crucial, as well as the education of STM employees in terms of dealing with different ethnicities, languages, and backgrounds are found. The chapter is a rare outside look at the STM and how users perceive the quality of the service, as opposed to the usual internal studies done by the organization itself.

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Supplier Selection Improvement Process in an XYZ Company Through DMAIC 312
Umangkumar Pabari, Concordia University, Canada

The existing supplier selection process of an XYZ company will be defined and mapped to understand the process characteristics and capabilities and then it will be analyzed to identify non-value-added activities. Corrective actions will be recommended to improve the supplier selection process for the company using DMAIC technique. It will aid in developing a competitive supplier base out of bulk suppliers available in the market that will result in competitive advantage over its peers and achieving the quality, cost, and service enrichment goals.

Chapter 16
Improving Bikesharing Service Quality: A Case Study for BIXI Montreal 341
Lakshmi Suvarchla Yalavarthi, Concordia University, Canada

Bike sharing is a typically structured non-motorized transportation service that provides users point-to-point transportation. The services are flexible to users as they do not have to wait in a line to pick up a bicycle from any bike sharing system and can return it to any other location of the bike sharing system. This chapter mainly focuses on why it is important to use bike sharing transportation rather than any other mode of transportation. In this chapter, the authors address the customer satisfaction level and focus on the service quality of the bike sharing system BIXI in Montreal. A questionnaire survey is conducted with the users of BIXI. A total of 580 responses are collected. Descriptive statistics, complaint analysis, and data analysis are done to identify areas of improvement.

Chapter 17
Risk Management in Supplier Selection: A FMEA-Based Approach for Retail Supply Chain 358
Zhong Hua Zhang, Concordia University, Canada
Ehsan Sharifnia, Concordia University, Canada

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Risk management issues have been widely researched in areas such as system engineering, business management, financial planning, market research, and service industry. Many approaches have been proposed to reduce or minimize risks, maintain productivity or profitability in organizations. However, different risk management strategies are needed under different situations and different industries. In this chapter, the authors address the theme of risk management in supply chains. They begin by reviewing the metrics of supply chain performance, followed by design and development of supplier relationship management process, and a failure modes and effects analysis (FMEA)-based approach to identify and evaluate the potential risks in the process of commodity procurement. After analyzing the causes and effects of potential risks in procurement, they develop a strategic plan to monitor and control risk management and implement continuous improvement. A case study is provided for supplier selection and buyer-supplier relationship management.

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Behnam Izadi, Concordia University, Canada

Shared mobility systems such as carsharing provide significant social and environmental benefits by reducing the number of vehicles used in the urban transport network. The carsharing systems are facing many challenges from the design to operation stages. In the design and strategic management level, it is important to find the best location for the stations, a minimum number of vehicles and a minimum number of operating staff, and in the operation stage, the most important problem is to relocate the vehicles moved by the members among the network to maximize the satisfied demands while the system is still economical. Effective and efficient optimization technology that can respond to user's demand is one of the necessary components for a successful carsharing system. The authors survey the related operations research models in the academic literature proposed to model different aspects of carsharing systems from a strategic and operational point of view to find the gaps and propose opportunities for new research.

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A TQM-Based Multi-Dimensional Approach to Improve the Quality of Supplier Selection in the Retail Industry 407
Ali Khabbazian, Concordia University, Canada
Manjot Singh Bhatia, Indian Institute of Management Lucknow, India
Zhonghua Zhang, Concordia University, Canada

In this chapter, the authors study risks in supply chain management, in the process of supplier selection for the procurement department of a retail supply chain. They propose a TQM-based multi-dimensional approach to improve supplier quality. They discover how the potential risks influence the performance of procurement in the supplier selection process of supplier relationship management. This chapter introduces a current supplier assessment approach by using weighted score ranking method as a single dimension mechanism for supplier selection in a specific retail industry. To estimate the efficiency of this mechanism, they use principal component analysis (PCA) statistical approach on real datasets to identify the most important factors that influence the decision-making of supplier selection. The strengths and weaknesses of this single dimension weighted ranking method are analyzed. The authors propose a total quality management (TQM)-based multi-dimensional mechanism to help the buyer identify, avoid, monitor, and reduce potential risks instead of using linear weighted score ranking method.

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Chapter 20
A Comprehensive Review on Advanced Maintenance Strategies for Smart Railways 433
Nastaran Enshaei, Concordia University, Canada
Amin Hammad, Concordia University, Canada
Farnoosh Naderkhani, Concordia University, Canada

Recently, energy efficient and sustainable supply chain has attracted a great deal of attention. To achieve sustainability, it is of paramount importance to use environmentally friendly procedures in each stage of the supply chain including suppliers, production/manufacturing, and transportation. Transportation plays a critical role in supply chain since the suppliers and customers are typically distributed in large geographical areas. Nowadays, railway is considered as a primary mode of transportation. Railways are considered as complex systems that are subject to degradation and failures. To avoid failures, tremendous efforts should be invested on preventive maintenance (PM) for performing optimal maintenance actions. Proper PM actions such as condition-based maintenance (CBM) play a major role in keeping the supply chain from crumbling down and working with high efficiency. This chapter reviews promising research works in the application of state-of-the-art CBM strategies that contribute to the advancement of smart transportation system via fault diagnostics/prognostics.

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Samia Hilal, Concordia University, Canada

Accurate and meaningful sharing of knowledge across the supply chain enables effective and timely decision making, a key requirement for ensuring cost-effectiveness, availability, and quality of products and services. Effective elicitation, analysis, classification, and representation of domain knowledge are all essential activities for effective sharing of information. Ontology-based frameworks create a common formal representation of a particular domain that can be communicated, and understood by people and machine agents in addition to integrating different knowledge bases to connect heterogeneous engineering applications. Such frameworks have been exploited in the manufacturing domain as buyer-supplier discovery systems that can be used for quick matchmaking, intelligent connectivity, knowledge-driven collaboration, and possible establishment of stronger, sustainable, long-term, and strategic supply chains. A literature review has identified many frameworks with varying knowledge sharing capabilities that are highly determined by the underlying ontological formalism.

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Mohammed A. Khasawneh, Concordia University, Canada

Almost every market in the world aims to go globally as wide as possible. It is important to understand the need for information and internet merged together in order to achieve such goal. Cloud systems are the new way of delivering and managing information to different parts in the world in a secure manner. However, not many organizations have moved to cloud. The rely of green supply chain management systems on cloud is not as popular as expected and not increasing fast enough. There is a trust issue raised against cloud and the adoption to it. Cloud can bring different benefits to green supply chain management

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systems such as the low cost of running, speed of dealing with information, and information availability which can have significant impact on energy savings. Organization contribution in the process of moving to cloud is important to attach any knowledge database to take competitive advantage.

Chapter 23
Demand Information Sharing for an Efficient Collaborative Supply Chain Planning 491
Suganya Jayapalan, Concordia University, Canada

Nowadays, many consumer goods manufacturers and retailers have understood the need to work together in order to elevate their performance. Such mutual cooperation, focusing beyond day-to-day business and transforming from a contract-based relationship to a value-based relationship is well received in the industries. Also, coupling information sharing in their collaborative setup is valued as an effective forward step. Moreover, advent of technologies naturally supports information sharing across the supply chain. As meeting consumers demand is the main aspect of supply chain, studying supply chain behavior with demand as a shared information makes it more beneficial. The chapter shall analyze demand information sharing in a two-stage supply chain with the performance measure being total cost in terms of profit. In order to quantify and understand better, the different levels of collaboration and their impact on the performance measure are analyzed using discrete event simulation. Arena software is used to simulate the required inventory control scenarios.

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Katarzyna Grzybowska, Poznan University of Technology, Poland
Bartosz Sobstyl, Independent Researcher, Poland

E-commerce is a fast-growing part of the market. Dynamic development of internet technology and increase of mobile devices popularity gives this branch very good perspective. E-commerce is still young. Trends on it are set by a few websites, which created this market, and which provide still new and innovative solutions to their customers. However, there are still more and more underdogs, who decided to focus on particular niches. This decision gives them a possibility to reach specific audience. More and more entrepreneurs noticed this trend and try to use it for their businesses. However, due to the number of new websites, selection of the proper one is not an easy task. The main goal of the chapter was to select the key factors, which will help entrepreneurs to choose the best platform for their needs.

Chapter 25
Security Framework for Supply-Chain Management 533
Kathick Raj Elangovan, Concordia University, Canada

In recent times, cyber-attacks have been a significant problem in any organization. It can damage the brand name if confidential data is compromised. A robust cybersecurity framework should be an essential aspect of any organization. This chapter talks about the security framework for cyber threats in supply chain management and discusses in detail the implementation of a secure environment through various controls. Today, a systematic method is used for handling sensitive information in an organization. It includes processes, people, and IT systems by implementing a risk management method. Distinct controls dedicated to different levels of domains, namely human resources, access control, asset management, cryptography, physical security, operations security, supplier relations, acquisition, incident management, and security governance are provided. Companies, contractors, and any others who are part of the supply chain organization must follow this security framework to defend from any cyber-attacks.

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Chapter 26
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Gul Pervez, Concordia University, Canada
Taiwo Olubunmi Adetiloye, Concordia University, Canada

In response to current economic downturn coupled with intense global competition, the concept of supply chain collaboration has emerged as a possible solution for firms aiming to gain competitive advantage through cost reduction, increased asset utilization and improving service levels. In this chapter, the authors address the problem of collaboration planning between multiple retailers and/or suppliers in a supply chain network. Three problems are considered, namely partner selection, collaboration strategy selection, and profit allocation, among the partners entering into a collaboration. Three techniques, namely cluster analysis, analytical network process (ANP), and game theory, are used for this purpose. Partner selection for collaboration is done using cluster analysis and analytical network process (ANP) while collaboration strategy selection is made through the application of game theory. The profit allocation among collaborating partners is performed using Shapley method. A numerical application is provided.

Chapter 27
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Rohit Parashar, Concordia University, Canada

The electrification of the vehicle has led to fundamental changes in the automotive value chain. Resulting in original equipment manufacturers (OEMs) to decide between manufacturing in-house and source the either product or component from joint ventures or suppliers. As electrical vehicle differs fundamentally from fuel-based counterparts, OEM must be adaptive with their manufacturing strategies. The value creation in the design is the replacement of engine-gear system with battery. Hence, battery is the critical component to be considered in manufacturing strategy. The decision making in finding less expensive and profitable way of either making the product or buying components from a capable supplier in global competitive environment is a serious discussion. In this chapter, the author is studying and applying the make or buy strategy to Tesla battery production.

Chapter 28
Multi-Tier Supplier Selection Using Total Cost of Ownership and Data Envelopment Analysis 597
Feras Saleh, Concordia University, Canada

Quality management across multiple tiers is vital to minimize cost of quality in global supply chains. In this chapter, the authors address the problem of supplier selection in multi-tier global supply chains with the purpose of overall quality management. A hybrid approach based on total cost of ownership (TCO) and network data envelopment analysis (DEA) is proposed. The TCO looks beyond the quoted cost to cover additional true costs related to the entire purchasing cycle. The cost categories included are quoted price, manufacturing costs, quality costs, design costs, logistics costs, after sales service, and social/environmental costs. Network DEA is used to rank the suppliers based on the TCO cost categories. The advantage of network DEA is its ability to investigate intermediate linkages between different stages of the supply chain. The results of network DEA are efficient suppliers and improvement targets for inefficient suppliers for improving overall quality in global supply chains. A numerical application is provided.

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Chapter 29
Location Planning of Electric Vehicles Charging Stations 623
Elnaz Moein, Concordia University, Canada

In this chapter, the authors address the problem of location planning of recharging stations for electric vehicles. This involves determining the best locations for charging stations in order to ensure that vehicles are charged enough for rendering a service when needed. The problem objective is to maximize the flow coverage for the electric vehicles through optimizing the number of recharging stations and their specific type at each station. Flow coverage is referred to as the ratio of car flows that are covered with regard to a special budget level. It also tries to minimize the locating cost related to these infrastructures. A genetic algorithm-based approach is proposed. Numerical application is provided, and results compared against branch and cut algorithm. The proposed approach performs better.

Chapter 30
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Jorge Luis García-Alcaráz, Autonomous University of Ciudad Juarez, Mexico
Aide A. Maldonado-Macías, Autonomous University of Ciudad Juarez, Mexico
Giner Alor-Hernández, Tecnologico Nacional de Mexico, Mexico
Pedro García-Alcaraz, Agricultural Technology Center School, Mexico
Emilio Jiménez-Macías, University of La Rioja, Spain

Supplier selection is a common practice in industrial sector and is usually conducted by engineers and administrators. However, in the healthcare sector, supplier selection is less commonly studied. This chapter proposes a methodology that simplifies the selection of suppliers in hospitals. As case study, the authors propose an example in which they evaluate six potential suppliers as alternatives with five attributes. The proposed methodology integrates the nominal group technique (NGT) to weight the attributes and dimensional analysis to estimate an index of similarity to an ideal supplier. This index of similarity is obtained from the best nominal values of the attributes. This methodology can be easily applied; it is intuitive and friendly to inexpert users, since the evaluation can be performed using a traditional spreadsheet. Also, the proposal allows for the simultaneous evaluation of multiple attributes and can be used by hospital administrators themselves, which prevents hospitals from hiring external services.

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Preface

Sustainable supply chains are vital for business growth, social coherence and environmental impact reduction. A number of initiatives have been launched in this direction such as green purchasing, cross-docking, clean transport, green packaging, health and safety measures, equal wages, industrial symbiosis, product service system, recycling etc. This book proposes interdisciplinary methods, tools and techniques for sustainable supply chain planning. Optimization, simulation, data mining, analytics, multi criteria decision making are used to address key problem areas in logistics, education, maritime, healthcare, agribusiness sectors etc.

The book is composed of thirty chapters organized under three main sections: Sustainability Management, Quality Management and Information management.

- The first section on sustainability management includes chapters with a focus on economic, environment and social pillars of sustainability. Problems of supplier selection, sustainability performance measurement, barriers in green supply chain planning, circular economy, electromobility, and carsharing are covered. Global supply chains is the highlight of this section.
- The second section addresses quality management in supply chains. Cost of quality, service quality management, risk management and six sigma applications for supply chains are covered. Numerical applications and case studies are provided.
- The third section addresses the theme of information management in supply chains. Very relevant, timely and critical problems in the context of modern supply chain management namely demand information sharing, e-commerce, cloud computing, collaboration planning and cybersecurity are discussed.

A brief description of the various chapters is provided as follows:

Chapter 1 presents a content analysis based literature review for global sustainable supplier selection. The supplier selection is investigated along four dimensions namely economic, environmental, social and global. The contingency analysis results show that environmental and social dimensions are moderately positively associated whereas a strong negative association exists between environmental and global criteria. This means that models tend to consider environmental and social criteria together in the supplier selection process. In contrast, models combining environmental considerations with global risk factors are rare.

Sustainability in industrial organizations has become a predominant concept in the 21st century due to environmental regulations, economic importance and social obligations. In this context, sustainable supplier selection plays an epochal role for taking strategic business decisions. So, a systematic approach

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is required to deal with the sustainable factors. Chapter 2 presents an integrated model for supplier selection from a sustainability perspective by integrating the three pillars (economic, environment, social). The proposed framework combines Analytic Hierarchy Process (AHP) and Quality Function Deployment (QFD) methods.

Chapter 3 presents a hybrid approach integrating rough set theory and QFD for benchmarking sustainability performance of suppliers against ISO 14001 criteria. Recently, green supply chain management has gained great interest from researchers and practitioners. Consideration has been given to consider environmental factors in entire supply chain starting from procurement, production, transportation, consumption, and post disposal of products to make the whole product life cycle green. And those companies implementing ISO 14001 are controlling and minimizing risks not only internally but also externally with their suppliers.

Chapter 4 provides a circular economy (CE) perspective for dairy supply chain. For over 20 years, sustainability attracted the main focus of most researchers; however, recently the concept of Circular Economy (CE) is considered to be its successor. CE is based on a closed loop supply chain, where waste is minimized and reintroduced into the supply chain, thus requiring a systemic change. In the agri-food sector, the CE principles have many possible applications. This chapter provides a CE Perspective for the Dairy Supply Chain by identifying and analyzing the associated technologies and strategies through a literature review taxonomy based on the related stage of the supply chain.

Chapter 5 proposes a multi-criteria framework for benchmarking sustainability performance of organizations. The indicators for evaluation are obtained using Sustainalytics database. Multicriteria decision making technique called TOPSIS (Technique for Order Performance by Similarity to Ideal) is used to generate organization rankings. The proposed technique is applied to evaluate performance of 24 companies in two major sectors: manufacturing and service. The selected companies come from the Canadian market. The results of TOPSIS study show manufacturing sector to be doing better than the service sector.

Chapter 6 studies the benefits of collaboration among shippers in less than truckload transportation and shows the role of transhipments in the collaboration. A new model for the Pickup and Delivery Problem with Transhipment and Time Windows is proposed. A transportation network with two transportation modes road and sea is considered. Different scenarios: with/without collaboration and with/without transhipment are optimised and compared on term of cost and CO2 emissions. A case study with real data from three agri-food companies in short sea shipping context is conducted. With this model, the total cost and the total amount of CO2 emissions are reduced by using collaboration and transhipment.

Chapter 7 addresses the problem of sustainability performance measurement of business organizations. Four main dimensions are considered namely organization, process, core and learning. A hybrid approach integrating sustainability scorecard framework and ANP is proposed for measuring overall organizational sustainability. GRI and Corporate Social Responsibility reports are used to obtain various indicators. The proposed sustainability scorecard provides a strong framework for improvement as the indicators used are industry specific, strongly supported by the core values and flexible.

Chapter 8 models barriers in green procurement using Interpretive Structural Modeling (ISM). Automotive industry from Iran and Canada are studied and barriers in green procurement identified. Three significant barriers for Iran are “financial and cost constraints”, “limitation in entering new technology, process and materials”, and “lack of a reverse logistics system in suppliers to decrease the price”. For Canada, the study illustrated “insufficient protecting of green procurement by top managements” and

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"insufficient realization and intention of end customers about green products" as the most significant barriers.

Chapter 9 presents a literature review on European Union Emissions Trading Scheme (EU-ETS). The European Union Emissions Trading Scheme (EU-ETS), launched in 2005, is one of the most important market-driven initiatives in support to the global commitment to fight the climate changes and foster sustainable development. The scheme design evolution, comprising four phases, was driven by continued ineffectiveness in driving emissions reduction, mainly for industries outside the power generation sector. This book chapter brings an analysis of the EU-ETS design evolution, aiming at providing an overview on how the EU-ETS design features improvements impacted its effectiveness.

Chapter 10 presents a literature review on electric carsharing. The recently observed increase in the number of car-sharing operators using a fleet of electric vehicles created an opportunity to expand existing ecological travel chains. Electromobility is one of travelling options that reduces the transport carbon footprint. The goal of the chapter is to draw attention to the need of using car-sharing to promote environmentally friendly behaviour and overcome concerns related to using an electric vehicle. The work presents the development of electric car-sharing in Europe and indicates challenges for further expansion of electromobility.

Chapter 11 presents a case study to analyze the Cost of Quality (COQ) in the supply chain process at Arctic North Inc., one of the winter jackets manufacturer in Montreal, Canada. Over the past decades, quality has become a key factor in customers' expectations. Organizations and businesses around the world are very interested in applying methodologies and techniques to reach higher quality levels since this will distinguish them from other competitors in the market. Furthermore, measuring the COQ in an organization is very important in order to be able to identify the problem of poor quality, quantify it, and analyze its causes to be able to solve it.

Chapter 12 addresses the theme of quality of food packaging. Various approaches based on new (N7) and basic (B7) tools of quality namely, cause and effect diagram, inter-relationship diagram and affinity diagram have been applied to understand and eliminate the root causes of the various problems being faced by the key supply chain players in the food packaging industry. The results show that the problem does not lie in the methods or techniques applied but in perspective and inclination of the management and key players of the food packaging supply chain towards the quality.

Chapter 13 provides a systematic framework for firms to achieve sustainability in manufacturing environment with the widely used problem solving tool Six Sigma. Most of manufacturing firms are medium and small sized, they are searching for a comprehensive and systematical way to implement sustainability practice step by step without using very experienced professionals. The proposed framework illustrates how to customize the six sigma DMAIC framework content based on individual needs. Inexperienced professionals will be able to implement the sustainability practice from defining problems to achieving leadership in sustainability.

Chapter 14 presents a hybrid approach based on SERVQUAL, SERVPERF and IPA for measuring transit service quality. The chapter discusses the public perception of the quality of service in the public transit system in Montreal using a combination of analyses and surveys. The results are used to make recommendations to improve the STM and its perception. A survey conducted among 250 international students yield improvement of timetable synchronization between different metro lines and buses, as well as the education of STM employees in terms of dealing with different ethnicities, languages, and backgrounds.

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Chapter 15 proposes a DMAIC based approach for supplier selection. The existing supplier selection process of the case company is mapped to understand the process characteristics and capabilities and identify non-value-added activities. Corrective actions are recommended to improve the supplier selection process for the company using DMAIC technique. It will aid in developing a competitive supplier base out of bulk suppliers available in the market that will result in competitive advantage over its peers and achieving the quality, cost and service enrichment goals.

Bike sharing is a typically structured non-motorized transportation service that provides users point-to-point transportation. The services are flexible to users as they do not have to wait in a line to pick up a bicycle from any bike sharing system and can return it any other location of the bike sharing system. Chapter 16 focuses on bike sharing transportation, customer satisfaction level and service quality of bike sharing. A questionnaire survey is conducted with the users of BIXI. Descriptive statistics, complaint analysis, and data analysis are done to identify areas of improvement.

Chapter 17 addresses the theme of risk management in supply chains. It begins by reviewing the metrics of supply chain performance, followed by design and development of supplier relationship management process, and a Failure Modes and Effects Analysis (FMEA) based approach to identify and evaluate the potential risks in the process of commodity procurement. After analyzing the causes and effects of potential risks in procurement, a strategic plan is developed to monitor and control risk management and implement continuous improvement. A case study is provided for supplier selection and buyer-supplier relationship management.

Chapter 18 provides a literature review on operations planning in carsharing systems. Shared mobility systems such as carsharing provide significant social and environmental benefits reducing the number of vehicles used in the urban transport network. Effective and efficient optimization technology that can respond to user's demand is one of the necessary components for a successful carsharing system. The chapter surveys the operations research models in the academic literature related to different aspects of carsharing systems from a strategic and operational point of view to find the gaps and propose opportunities for new research.

Chapter 19 studies risks in procurement in supply chain management. The supplier selection process for a retail supply chain is investigated. A Total Quality Management (TQM) based multi-dimension approach is proposed to improve supplier quality. Principal Component Analysis (PCA) statistical approach is used to identify the most important factors that influence the decision-making of supplier selection. Linear weighted scoring method is used to rank the suppliers. The proposed approach can based multi-dimension mechanism to help the buyer identify, avoid, monitor and reduce potential risks, instead of using linear weighted score ranking method.

Chapter 20 is dedicated to a comprehensive review on advanced maintenance strategies for smart railways. To achieve sustainability, it is of paramount importance to use environmentally friendly procedures in each stage of the supply chain including suppliers, production/manufacturing, and transportation. To avoid failures, tremendous efforts should be invested on preventive maintenance (PM) for performing optimal maintenance actions. This book chapter reviews promising research works in the application of state-of-the-art Condition Based Maintenance (CBM) strategies that contribute to the advancement of smart transportation system via fault diagnostics/prognostics.

Chapter 21 conducts a survey of ontology-based frameworks for sustainable supply chain interoperability & collaboration. Effective elicitation, analysis, classification, and representation of domain knowledge are all essential activities for effective sharing of information. Ontology-based frameworks create a common formal representation of a particular domain that can be communicated, understood by

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people and machine agents in addition to integrating different knowledge bases to connect heterogeneous engineering applications.

Chapter 22 investigates the impact of cloud computing on green supply chain management. Cloud systems are the new way of delivering and managing information to different parts in the world in a secure manner. However, not many organizations have moved to cloud. There is a trust issue. Cloud can bring different benefits to green supply chain management systems such as the low cost of running, speed of dealing with information and information availability which can have significant impact on energy savings.

Chapter 23 addresses the theme of demand information sharing for an efficient collaborative supply chain. Different levels of information sharing namely full, partial, and none are simulated and their impact on the performance measures analyzed. Discrete event simulation is performed using Arena software to simulate the various inventory control scenarios.

E-commerce is a fast-growing part of market. Dynamic development of Internet technology and increase of mobile devices popularity gives this branch very good perspective. E-commerce is still young. Trends on it are set by a few websites, which created this market, and which provide still new and innovative solutions to their customers. However, due to the number of new websites, selection of the proper one is not an easy task. The main goal of Chapter 24 is to select the key factors, which will help entrepreneurs to choose the best platform for their needs.

Chapter 25 presents a security framework for supply chain management. In recent times, cyber-attacks have become a significant problem in any organization. It can damage the brand name if confidential data is compromised. A robust cybersecurity framework should be an essential aspect of any organization. The chapter talks about the security framework to minimize cyber threats in supply chain management and discusses the implementation of a secure environment through various controls in detail.

In response to current economic downturn coupled with intense global competition, the concept of supply chain collaboration has emerged as a possible solution for firms aiming to gain competitive advantage through cost reduction, increased asset utilization and improving service levels. Chapter 26 addresses the problem of collaboration planning between multiple retailers and/or suppliers in a supply chain network. Three problems are considered namely partner selection, collaboration strategy selection, and profit allocation among the partners entering into a collaboration. Cluster analysis, analytical network process (ANP) and game theory are used. A numerical application is provided.

The electrification of the vehicle has led to fundamental changes in the automotive value chain. Resulting in original equipment manufacturers (OEMs) to decide between manufacturing in-house and source the either product or component from joint ventures or suppliers. Chapter 27 investigates Make or Buy approaches for batteries used in electric cars. The decision making in finding find less expensive and profitable way of either making the product or buying components from a capable supplier in global competitive environment is a serious discussion.

Chapter 28 presents a hybrid approach based on Total Cost of Ownership (TCO) and network Data Envelopment Analysis (DEA) for multi-tier supplier selection. The TCO looks beyond the quoted cost to cover additional true costs related to the entire purchasing cycle. The cost categories included are quoted price, manufacturing costs, quality costs, design costs, logistics costs, after sales service, and social/environmental costs. Network DEA is used to rank the suppliers based on the TCO cost categories. A numerical application is provided.

Chapter 29 addresses the problem of location planning of recharging stations for electric vehicles. This involves determining the best locations for charging stations in order to ensure that vehicles are

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charged enough for rendering a service when needed. The problem objective is to maximize the flow coverage for the electric vehicles through optimizing the number of recharging stations and their specific type at each station. Flow coverage is referred to as the ratio of car flows that are covered with regard to a special budget level. Locating cost related to these infrastructures is minimized. A genetic algorithm based approach is proposed. Numerical application is provided and results compared against branch and cut algorithm. The proposed approach performs better.

Supplier selection is a common practice in industrial sector and is usually conducted by engineers and administrators. However, in the healthcare sector, supplier selection is less commonly studied. Chapter 30 proposes a methodology that simplifies the selection of suppliers in hospitals. An example of six potential suppliers as alternatives with five attributes is provided. The proposed methodology integrates the nominal group technique (NGT) to weight the attributes and dimensional analysis to estimate an index of similarity to an ideal supplier. This index of similarity is obtained from the best nominal values of the attributes. This methodology can be easily applied, is intuitive and friendly to inexpert users.

The book provides novel interdisciplinary approaches to address key problems in sustainable supply chain management. The presented works can be used to devise new policies, design networks, perform strategic supplier selection, develop effective reverse logistics practices and optimize system performance from socio-economic-environmental perspectives. It will serve as a very useful resource for academicians and practitioners in the area.

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Section 1
Sustainability Management

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Chapter 1
Global Sustainable Supplier Selection: A Literature Review

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ABSTRACT

Supplier selection is critical for sustainability management in global supply chains. In this chapter, the authors present a content analysis based literature review for global sustainable supplier selection. The supplier selection is investigated along four dimensions, namely economic, environmental, social, and global. The results of the study yield that environmental and social criteria are often used together for supplier selection whereas global risk criteria are rarely used, even less as we move along multiple tiers of the supply chain. From the review, the authors also identified the top criteria along these four dimensions for global sustainable supplier selection. Along the economic dimension, the top three criteria are quality, cost, and general supplier characteristics. The social dimension has employees, transparency and engagement, and local communities' influence as the top criteria. Along the environmental dimension, the top criteria are pollution and hazardous emissions, standards and management systems, green product and design, and green competencies and processes. The top criteria along the global dimension are distance, other risks, and politics and economy.

INTRODUCTION

Supplier selection is an established field in operations research. De Boer et al. (2001) define problem definition, criteria selection, pre-selection of candidates, and final decision as the four phases of the supplier selection process. Problem definition and category and criteria selection can be addressed by qualitative and quantitative methods. Example of qualitative method are brainstorming or visual analysis

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that can be applied in pre-selection; in contrast, quantitative methods are used for more fine-grained category selection and making final decision. Examples of quantitative methods are various kinds of mathematical programming models such as Linear, goal, and multi-objective programming, analytical hierarchy and network process (AHP/ANP), data envelopment analysis (DEA), simple multi-attribute rating technique (SMART), artificial neural networks, and various integrated solutions combining those approaches (De Boer et al., 2001; Ho et al., 2010; Agarwal et al., 2011).

The models proposed for solving the supplier selection problem so far are largely limited to the simple case of domestic sourcing and hence often neglect the specific risks of global sourcing (Chan and Kumar, 2007). With the concept of sustainable development entering into the political and business arena since the late 1980s (WCED, 1987), sustainability-related information has been successively included into the supplier selection process (e.g., Handfield et al., 2002; Bai and Sarkis, 2010; Shaw et al., 2013). During the last decade, a corpus of papers which incorporate global risks and sustainability issues into supplier selection models has emerged in operations research literature (Zimmer et al., 2017, Vahidi et al., 2018, Alikhani et al., 2019). However, there are currently very few studies that address this critical problem of beyond first tier suppliers at all and even less that suggest a systematic methodological procedure for supplier selection considering various sub-supplier levels (Gold and Awasthi, 2015).

In this paper, we address the theme of global sustainable supplier selection. For the purpose of this study, we define supplier selection models as one that integrate specific risks from global sourcing with sustainability performance criteria operationalized as triple bottom line (economic, environmental, social) (Dyllick and Hockerts 2002). Further, we investigate how far supplier selection models incorporate risks from beyond first tier suppliers (i.e. from second tier suppliers and suppliers further up the chain). Recent research has shown that it is not enough for focal companies to manage their direct suppliers since major sustainability problems are often linked to their supply chain further upstream (Grimm et al., 2014). Focal companies are held responsible for the misconducts of these beyond first tier suppliers, potentially leading to consumer anger and boycotts (Hartmann and Moeller, 2014). Despite these substantial risks involved, multi-tier supply chains have been barely considered in SCM research (Tachizawa and Wong, 2014) and even less in supplier selection models in operations research (Awasthi et al., 2018).

The remainder of the paper is structured as follows. Section 2 presents the methodology of the literature review. We then provide a descriptive analysis of main features of the paper sample, followed by a systematic review of supplier selection techniques, supplier selection criteria and industrial focus of the papers in section 3. The condensed findings of this analysis are presented qualitatively along with frequency and contingency analysis in section 4. Finally, we conclude our paper with promising avenues for future research in section 5.

RESEARCH METHODOLOGY

The procedure of doing a literature review as content analysis has previously been adopted in the fields of operations research (Brandenburg, 2014); its application in the field of supply chain management has been discussed in-depth by Seuring and Gold (2012). According to Fink (2005), a research literature review represents a rule-governed and traceable design for identifying and assessing a corpus of scholarly works in a certain field (Fink, 2005). A literature review hence evaluates research that has originated around a specific topic; in this way, it sheds light on the state-of-the-art of academic knowledge and may be considered an indispensable component – and is often regarded the initial step – in the theory

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development process (Mentzer and Kahn, 1995). While an early definition by Berelson (1955) considers content analysis as a quantitative tool for investigating manifest content of communications, this method has subsequently broadened its application field and has gained a strong qualitative side (Shapiro and Markoff, 1997; Mayring, 2000). Content analysis is predicated on theoretical pre-considerations and a clear research procedure (Kassarjian, 1977). We follow a four-step process model as suggested by Seuring and Gold (2012) (mainly referring to Mayring, 2008). Such segmentation into various steps enhances the traceability of results, in contrast to hermeneutic and other interpretative methods (Duriau et al., 2007; Seuring and Gold, 2012)

Material Collection

We analyse global sustainable supplier selection models that have been published in English-speaking peer-reviewed journals, with special focus on operations management/research journals, between 2000 and 2014. We excluded conference papers, conference reviews, errata, and book chapters and non-English articles. Taking peer-reviewed journal articles as the unit of analysis makes sense since they constitute the main mode of communication among scholars of a research programme; in addition, the peer review process ensures that the supplier selection models presented feature some minimal quality standards and fit into the respective research programme.

In order to compile a sample of most relevant papers dealing with sustainable global supplier selection, we followed a two-step search procedure. In a first step, literature search was conducted based on various combinations of descriptors or labels as described in Table 1. A preliminary screening of peer-reviewed English-speaking articles found that supplier selection models incorporating sustainability and/or global sourcing risks are traded under a rather large variety of labels; thereby the most common labels are global supplier selection and green supplier selection. We used the results of this preliminary screening for defining combinations of keywords for the subsequent structured keyword research (see Table 1). If any combination of the various terms listed in the columns of Table 1 were found together in title, keywords or abstract as separate strings, the paper was retrieved. Then these papers were filtered for duplicates and through a list of most relevant journals in the area of decision science borrowed from Hassini et al. (2012) (Table 2). In a second step, the search was repeated by the same descriptors as listed in Table 1, to be found as one single string, as for example “global supplier selection”.

Table 1. Descriptors for structured key word research

Group 1 descriptors	Group 2 descriptors	Group 3 descriptors
“global”	“supplier”	“selection”
“international”	“vendor”	“performance evaluation”
“sustainable”		“scoring model”
“green”		“ranking generation”
“environmental”		“vendor selection”
“social”		“performance evaluation”
		“scoring model”
		“ranking generation”

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Table 2. List of OM and OR journals

Journals
Computers in Industry
Enterprise Information Systems
European Journal of Operational Research
Foundations and Trends® in Technology, Information and Operations Management
Interfaces
International Journal of Information Management
International Journal of Logistics Research and Applications
International Journal of Logistics Systems and Management
International Journal of Management and Decision Making
International Journal of Management and Enterprise Development
International Journal of Operational Research
International Journal of Operations and Production Management
International Journal of Process Management and Benchmarking
International Journal of Product Lifecycle Management
International Journal of Production Economics
International Journal of Production Research
International Journal of Risk Assessment and Management
International Journal of Services and Operations Management
International Journal of Technology Management
Journal of Operations Management
Journal of the Operational Research Society
Management Science
Omega
Production and Operations Management
Production Planning and Control
TQM Journal
Transportation Research Part E: Logistics and Transportation Review

The results from the two search steps were eventually combined and subsequently checked for relevance. Papers that could not be accessed by the authors (namely those published by Inderscience) were requested directly from the authors; 9 papers, however, could not be retrieved. Altogether, we identified 36 articles. Figure 1 depicts the main steps of the literature research process. We limited the literature research to the Scopus database since it embraces all the journals of our journal lists and many more OM and OR journals; Scopus can be regarded a rather comprehensive database in particular for research published after 1995 (Falagas et al., 2008).

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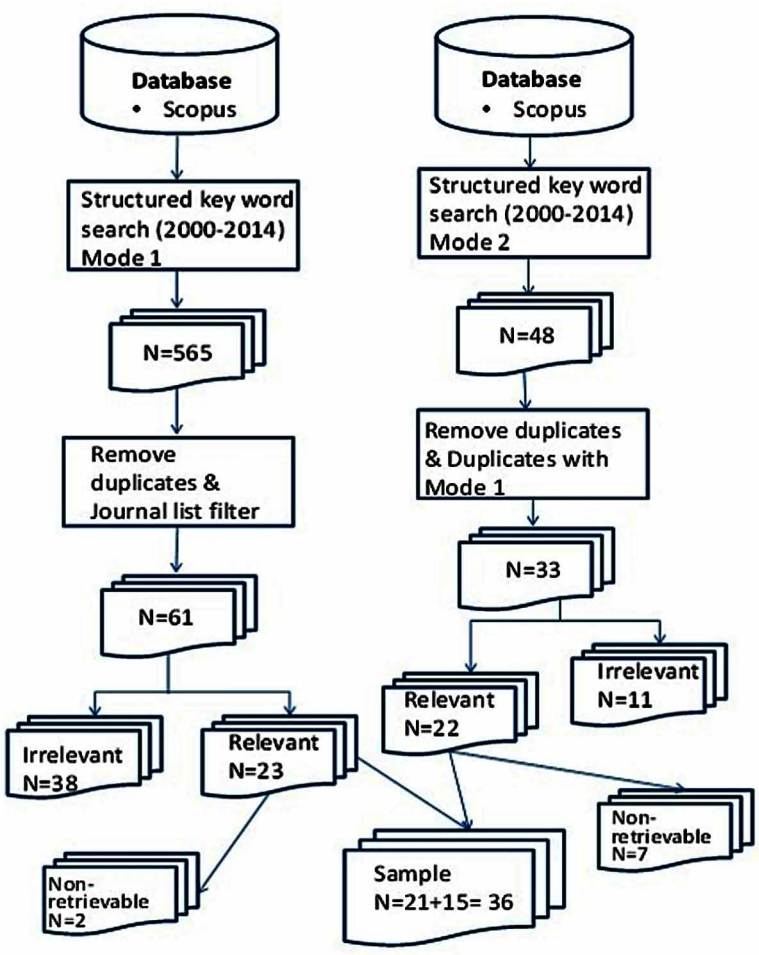
Figure 1. Main steps of the literature search process



Descriptive Analysis

Formal aspects of the paper sample are assessed in a descriptive analysis. Characteristics considered in the frame of this paper are year of publication, publication outlet, and country of authors' affiliation.

Category Selection and Material Evaluation

For investigating global sustainable supplier selection models, we specifically look at four categories: (1) Supplier selection technique applied, (2) dimensions of supplier selection criteria, (3) industrial focus, and (4) detailed overview of supplier selection criteria. Thereby, dimensions of supplier selection criteria follows a classification commonly used in literature, comprising economic and operational, environmental, and social as the three pillars of the Triple Bottom Line approach by which sustainability is often operationalized in particular in the business realm (Dyllick and Hockerts, 2002). As fourth dimension, we add global risk factors, in accordance with our double focus on sustainable and global supplier selec-

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tion models. Information concerning these four analytic categories is systematically retrieved from the sample of articles and sorted in Excel spreadsheets.

Contingency Analysis

Data collected by content analysis may be further processed by qualitative synthesis as well as frequency tables, which can be evaluated by statistical methods as for example contingency analyses (cf. Gold et al., 2010 for a similar approach). Contingency analysis reveals positive/negative association patterns between categories by assessing whether a pair of criteria occurs together in one paper more/less often than the product of their single probabilities of occurrence would suggest. For two-by-two contingency tables with small frequency counts, this association is best measured by the rather robust Fisher's Exact Test (Mehta and Patel, 1983). The strength of this positive/negative association is denominated by the Phi-coefficient (ϕ); when ϕ exceeds 0.3 or -0.3, the relationship may be considered as non-trivial (Backhaus, 2008). Therefore, we only report relationships between category pairs for which $\phi \geq 0.3$ or $\phi \leq -0.3$ and the respective significance ≤ 0.05, indicating the probability of falsely rejecting the hypothesis of independence between the pair of categories. It needs to be noted though that this measure of association does not indicate any direction of relationship.

FINDINGS

This section presents the findings from structured content analysis, beginning with the descriptive analysis.

Findings From Descriptive Analysis

Table 3 shows that articles are spread over a wide range of journals. By far most articles are published in the International Journal of Production Research (10), followed by the International Journal of Production Economics (3), the Journal of Cleaner Production (3), and Omega (2). The remaining 16 articles are evenly distributed over further 16 journals in the area of OM, OR, engineering, and (applied) mathematics. It needs to be considered that this list is biased towards the list of journals used for filtering results obtained by the first search mode.

Looking at the distribution of articles over the time span 2000-2014, it is striking that publications on sustainable and global supplier selection models are only hesitantly starting in 2007 and gaining momentum in 2010. The peak is in 2014, even though publications for 2014 are not completely recorded since literature search has been carried out in August 2014. It may be concluded that sustainable and global supplier selection models are a rather new phenomenon responding to contemporary phenomena in the business environment, namely increasing outsourcing in geographically and culturally distanced countries and increasing pressures (from consumers, governments and civil society in large) to include sustainability considerations when choosing suppliers.

Figure 3 presents an overview of countries to which authors are affiliated. Country scores are calculated by evenly splitting authorship among all authors; this means that for example a publication by four authors who are from four different countries would contribute a score of 0.25 to each country. The diagram shows that problems of global and sustainable supplier selection are rather popular in Taiwan

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Table 3. Distribution of articles across journals

Journal	Frequency
International Journal of Production Research	10
International Journal of Production Economics	3
Journal of Cleaner Production	3
Omega	2
Expert Systems with Applications	2
International Journal of Logistics Systems and Management	1
Computers and Operations Research	1
European Journal of Operational Research	1
Computers and Industrial Engineering	1
Journal of Manufacturing Technology Management	1
Computers in Industry	1
International Journal of Operational Research	1
Quality and Quantity	1
BioTechnology: An Indian Journal	1
Applied Soft Computing Journal	1
Advances in Fuzzy Systems	1
International Journal of Industrial Engineering Computations	1
Journal of Grey System	1
International Journal of Precision Engineering and Manufacturing-Green Technology	1
Advances in Information Sciences and Service Sciences	1
Journal of Testing and Evaluation	1

Figure 2. Distribution of articles across the time period 2000-2014

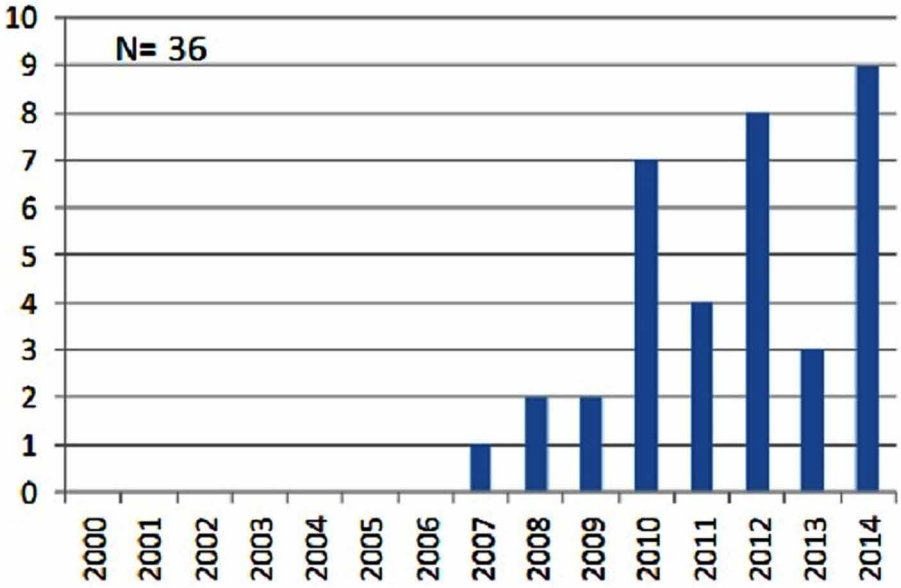

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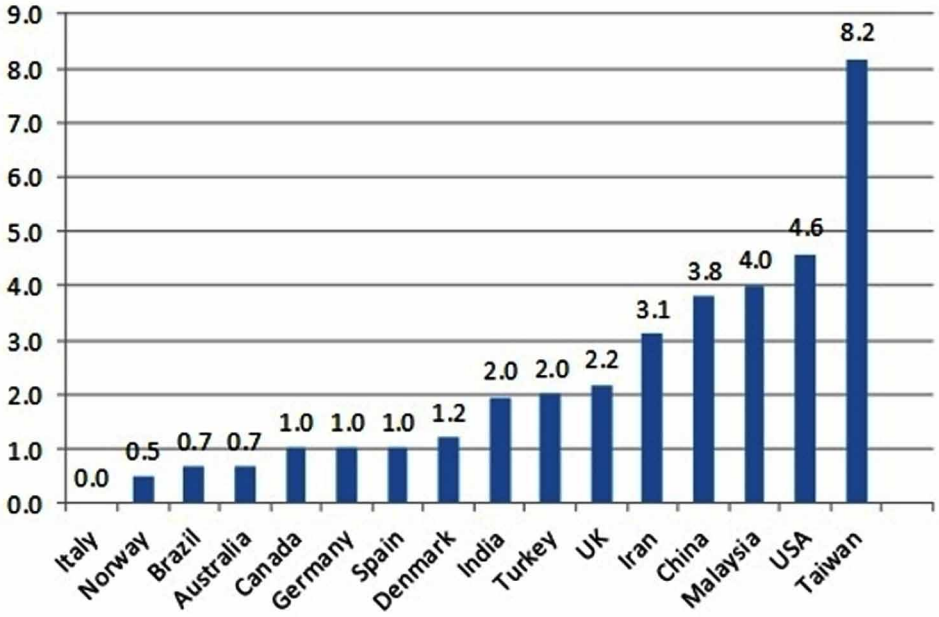
Figure 3. Distribution of authorship affiliation across countries



(8.2), the USA (4.6), Malaysia (4.0), China (3.8) and Iran (3.1). Normalized to the countries' size of population, these topics appear to arouse particular interest in Taiwan, Malaysia, and Iran.

Supplier Selection Criteria

The four categories of economic, social, environmental, and global risks are addressed to different degrees by our sample of supplier selection models. Indicators reported by our literature sample have been inductively classified in main categories, without entirely excluding partial overlaps between the main categories of one supplier selection dimension, and even between categories across different supplier selection dimensions (economic & operational, environmental, social, global). A detailed list of criteria can be found in Tables 6 through 9 in the Appendix.

Figure 4 shows the main categories of the supplier selection dimension of economic or operational criteria; cost (e.g., purchasing cost, cost of shipment / freight / logistics, tariff and taxes), dependability (e.g., delivery reliability, delivery schedule, order fulfilment rate), flexibility (e.g., prompt response, response to changes, volume flexibility), innovativeness (e.g., capability of research & development, suppliers design capability, new launch of products), quality (e.g., conformance quality / product quality, quality assessment / assurance, rejection / defective rate of the product), relationship (e.g., ease of communication / communication openness, conflict resolution, efficient IT-interfaces / Electronic Data Interchange), speed (e.g., lead-time, product development time, delivery speed), technology and processes (e.g., technology / technological capability / compatibility, production facility and capacity, process capability), and general supplier characteristics (e.g., financial capability / performance, organization / organizational structure, performance history & past business). It can be seen that among the top five economic or operational criteria, quality ranks the highest followed by cost, relationship, general supplier characteristics and dependability.

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Figure 4. Main categories of economic or operational supplier selection criteria with frequencies

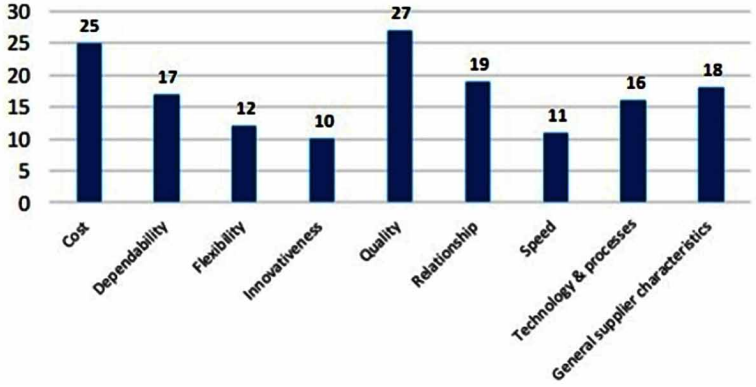

Figure 5 shows the main environmental supplier selection categories; these categories include green communication and information exchange (e.g., carbon accounting and inventory, information sharing, staff training), green competencies and processes (e.g., green / environmental (process) planning, environmental (management) competencies, checking and evaluation of environmental activities), green management of own suppliers (e.g., green purchasing / supply chain management, passing ISO 14000 verification of suppliers, having environmental protection policies of suppliers), green product and design (e.g., green design / design for the environment, green product, green packaging), pollution and hazardous emissions (e.g., pollution control, solid waste, GHG emissions / carbon footprint), recycling (e.g., recycling / reusing / re-manufacturing capability / level, reverse logistics / returns handling capability, cost of component disposal), resources (e.g., energy consumption, water consumption, raw material consumption), standards and management systems (e.g., environmental management system such as ISO 14001, establishment of environmental commitment and policy, number of obtained ISO standards), and general green risks (e.g., green image, environmental costs, green customer's purchasing retention). It can be seen that among the top five environmental criteria, pollution and hazardous emissions ranks the highest followed by standards and management systems, green competencies and processes, green product and design, and general green risks.

Figure 5. Main categories of environmental supplier selection criteria with frequencies

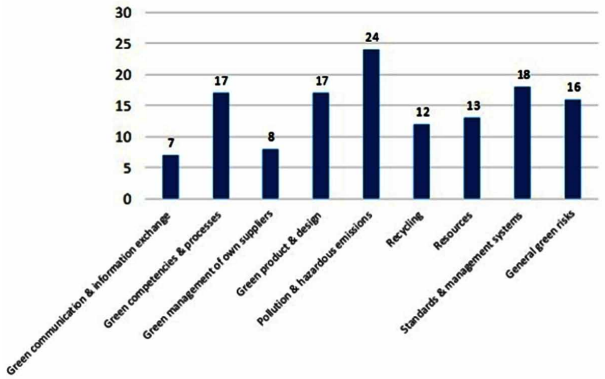

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Figure 6. Main categories of social supplier selection criteria with frequencies

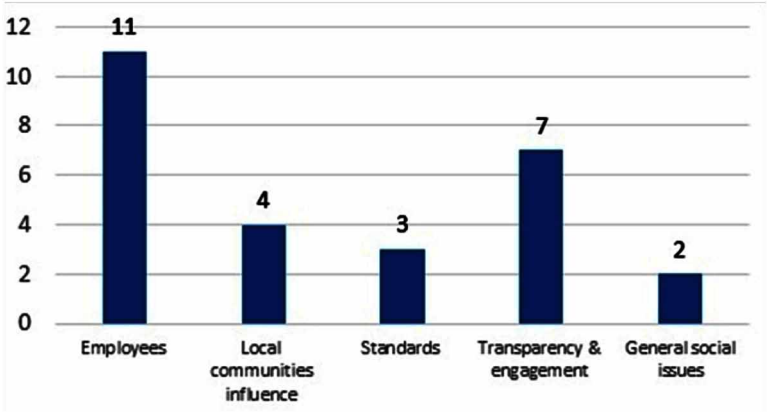
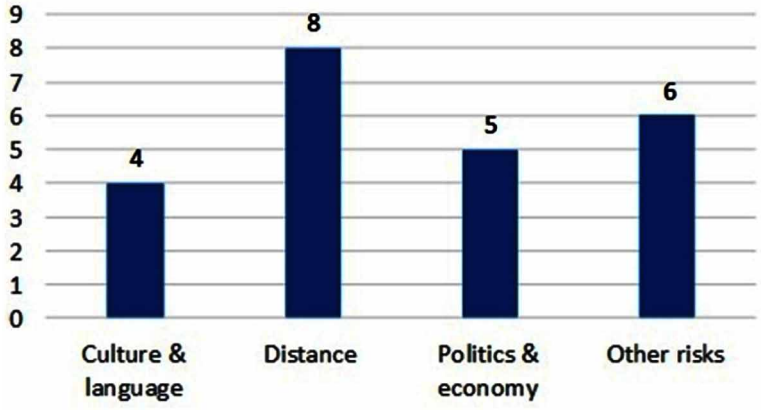


Figure 6 synthesizes indicators of the social supplier selection dimension into main categories; namely employees (e.g., work safety and labour health, interests and rights of employees, job opportunities / creation), local community influence (e.g., education, housing, mobility infrastructure), standards (e.g., partnership screens and standard, procurement standard, performance against EU sustainability assurance standards), transparency and engagement (e.g., information disclosure, rights of stakeholders such as shareholders, consumers, communities, stakeholder empowerment), and general social issues (e.g., sustainable image, social responsibility). It can be seen that among the top five social criteria, employees ranks the highest followed by transparency and engagement, local communities influence, standards, and general social issues.

Figure 7 depicts main categories of global risks, i.e. distance (e.g., geographical location, reliability of logistics providers, difficulty of cross-location coordination), politics and economy (e.g., political stability, exchange rate, terrorism), culture and language (cultural and communication barriers, cultural similarities and differences, language), and other global risks (e.g., visibility of supply chain, reliability of the supplier's suppliers, dependency on imports). It can be seen that among the top ranked criteria is distance followed by other risks, politics and economy, and culture and language.

Figure 7. Main categories of global supplier selection criteria with frequencies



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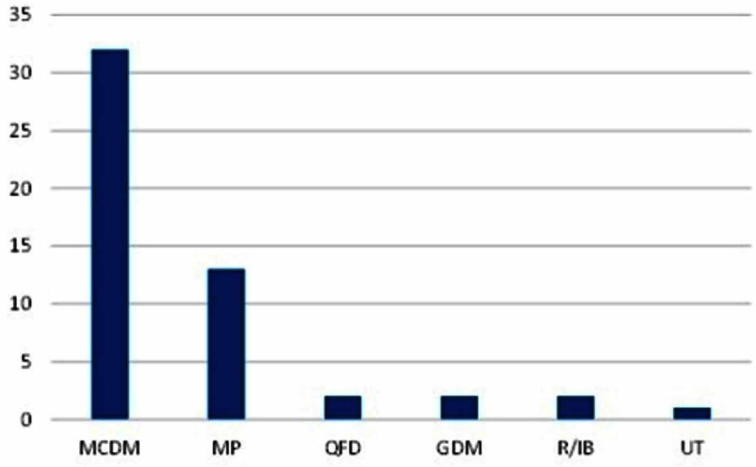
Findings From Content Analysis

Table 4 gives an overview of supplier selection technique, dimensions of supplier selection criteria, and the industrial focus. The most widely used models for supplier selection are analytic models of multi-criteria decision-making. The solution methods are dominated by the analytical hierarchy process (AHP) technique, in its fuzzy extension or its variant analytical network process (ANP). AHP is often integrated with data envelopment analysis (DEA), another multicriteria decision making method, or group decision-making techniques such as Delphi, and models of multi-objective mathematical programming (often solved in the form of goal programming). Finally, researchers occasionally attempt to base the solution of their supplier selection problem (partly) on various heuristic methods; these heuristics comprise both the technique of artificial intelligence (fuzzy logic, neural network, rough set) and meta-heuristics (genetic algorithm, particle swarm optimization). Figure 8 gives an overview of the method categories used in our literature sample.

Regarding supplier selection criteria, economic and operational criteria as well as environmental criteria are addressed in the majority of our paper sample (29); social criteria seem to be more difficult to be integrated in sustainable supplier selection models (cf. Seuring, 2013) (13); finally, it appears that the consideration of global risks is still in its infancy (7); nonetheless, changing business realities through increasing outsourcing in distanced countries call for strengthening global risk assessment as integral component of supplier selection.

Figure 8. Widely used models for supplier selection



Box 1.

MCDM	Multi-criteria decision-making	GDM	Group decision making
MP	Mathematical programming	R/IB	Rule/inference based
QFD	Quality function deployment	UT	Utility theory

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In terms of industry focus it is worth noting that one third of papers are purely numerical (12), without any sort of practical application. Popular industries for application cases are the electrical and electronics industry (10), followed by the automotive industry (3) and chemical industry (3).

Further, we investigate how far supplier selection models incorporate risks from beyond first tier suppliers (i.e. from second tier suppliers and suppliers further up the chain). Recent research has shown that it is not enough for focal companies to manage their direct suppliers since major sustainability problems are often linked to their supply chain further upstream (Grimm et al., 2014). Focal companies are held responsible for the misconducts of these beyond first tier suppliers, potentially leading to consumer anger and boycotts (Hartmann and Moeller, 2014). Despite these substantial risks involved, multi-tier supply chains have been barely considered in SCM research (Tachizawa and Wong, 2014) and even less in supplier selection models in operations research. Our literature review finds only 11 selection models, which contain criteria that allude in some way to risks connected to beyond first tier suppliers. This is often done by including a criterion named green purchasing or green supply chain management (Amindoust et al., 2012b; Beng and Omar, 2014; Dai and Blackhurst, 2012; Kannan et al.; 2014a; Kuo and Lin, 2012; Lee et al., 2011), referring rather generally to the direct supplier's own supplier selection and management capabilities and policies. Kannan et al. (2014a) specifically regards the evaluation of the environmental management of the second tier suppliers. Che (2010) and Yeh and Chuang (2011) include the criteria of passing ISO 14000 verification of suppliers and having environmental protection policies / plans of suppliers, respectively. Further, Levary (2008) examines the reliability of supplier's suppliers; Wittstruck and Teuteberg (2012) include beyond first tier suppliers by evaluating the information sharing level in sub-tier suppliers, and Scott et al. (2013) assess the visibility of the supply chain.

Table 4. Overview of supplier selection technique, supplier selection criteria, and industrial focus

		Supplier selection criteria				
Authors	**Supplier selection technique**	**Economic or operational**	**Environmental**	**Social**	**Global**	**Industrial focus**
Amindoust et al. (2012a)	DEA	X	X	X		Palm-oil production
Amindoust et al. (2012b)	Fuzzy inference system (FIS)	X	X	X		No specific
Arshadi Khamseh and Mahmoodi (2014)	Fuzzy time function; fuzzy TOPSIS-TODIM (TODIM: interactive and multi-criteria decision-making)		X			No specific
Awasthi et al. (2010)	TOPSIS		X			No specific
Azadi et al. (2014)	DEA; enhanced Russell measure (ERM)	X	X	X		Chemical industry
Azadnia et al. (2014)	Rule-based weighted fuzzy method; fuzzy AHP; MOMP	X	X	X		Food packaging
Bai and Sarkis (2010)	Grey-based rough set methodology	X	X	X		No specific
Beng and Omar (2014)	Fuzzy AD		X			No specific
Büyüközkan (2012)	AHP; AD-based fuzzy group decision-making approach	X	X			Automotive industry
Büyüközkan and Çifçi (2011)	ANP; multi-person decision-making schema	X	X	X		White goods industry
Chan et al. (2008)	Fuzzy AHP	X			X	No specific

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Table 4. Continued

		Supplier selection criteria				
Authors	**Supplier selection technique**	**Economic or operational**	**Environmental**	**Social**	**Global**	**Industrial focus**
Chan and Kumar (2007)	Fuzzy AHP	X			X	No specific
Che (2010), Che (2010)	AHP; transformation technique; particle swarm optimisation (PSO)	X	X			Electrical and electronics industry
Dai and Blackhurst (2012)	AHP; quality function deployment (QFD)		X	X		Retailing
Dou and Sarkis (2010)	ANP	X	X	X		No specific
Hashemi et al. (2014)	Grey-based model		X			No specific
Kannan et al. (2014a)	Fuzzy TOPSIS; geometric mean based fuzzy TOPSIS; graded mean integration fuzzy TOPSIS		X			Electrical and electronics industry
Kannan et al. (2014b)	Fuzzy AD; MOMP	X	X	X		Chemical industry
Kannan et al. (2013)	Fuzzy multi attribute utility theory; MOMP	X	X			No specific
Ku et al. (2010)	Fuzzy AHP; fuzzy goal programming (GP)	X			X	Electrical and electronics industry
Kumar et al. (2014), Kumar et al.(2014)	Green DEA	X	X			Automotive industry
Kuo and Lin (2012)	ANP; DEA	X	X			Electrical and electronics industry
Kuo et al. (2010)	Artificial neural network (ANN); ANP; DEA	X	X	X		Electrical and electronics industry
Lee (2009)	Fuzzy AHP	X				Electrical and electronics industry
Lee et al. (2009)	Fuzzy extended AHP; Delphi study	X	X			Electrical and electronics industry
Lee et al. (2011)	Fuzzy AHP	X	X			Hand tool industry
Levary (2008)	AHP	X			X	No specific
Lin et al. (2012), Lin et al.(2012)	ANP; linear programming (LP)	X	X			Electrical and electronics industry
Ravindran et al. (2010)	Pre-emptive; non-pre-emptive; Tchebycheff; fuzzy goal programming (GP)	X				Electrical and electronics industry
Scott et al. (2013)	AHP; quality function deployment (QFD)	X	X	X	X	Bioenergy industry
Shaw et al. (2013)	AHP; multi-objective fuzzy linear programming	X	X	X	X	No specific
Tse and Tan (2011)	Margin incremental analysis (MIA)				X	Toy manufacturing
Wittstruck and Teuteberg (2012)	Fuzzy AHP; TOPSIS	X	X	X		Recycling
Yazdani (2014)	AHP; fuzzy TOPSIS	X	X			Automotive industry
Yeh and Chuang (2011)	Multi-objective genetic algorithm	X	X			Electrical and electronics industry
Zhou et al. (2012)	ANP; radial basis function (RBF) neural network	X	X			Chemical industry
		$\Sigma = 29$	$\Sigma = 29$	$\Sigma = 13$	$\Sigma = 7$	

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Box 2.

Abbreviations
AHP: Analytical hierarchy process.
ANP: Analytical network process.
DEA: Data envelopment analysis.
MOMP: Multi-objective mathematical programming.
AD: Axiomatic design.

Contingency Analysis

Having a closer look at the four dimensions of supplier selection criteria by means of a contingency analysis (Table 5), it becomes clear that the environmental and social dimensions are moderately positively associated (φ= .369). Hence, researchers tend to include both into their models or leave both out. In addition, it is striking, that social criteria are only considered if also environmental criteria are considered (in 13 cases), however not vice versa; i.e. environmental criteria are considered without social criteria in 16 cases. This indicates that social criteria are still taking a backseat in sustainable supplier selection models, and are mostly introduced as part of Triple Bottom Line thinking.

In addition, the analysis shows a rather strong negative association between environmental and global criteria (φ=.-645); this means that models combining environmental considerations with global risk factors are still rather rare. Researchers rather tend to decide whether they build a sustainability-focussed model or a global-sourcing model. This lack of comprehensive models is reflected by only two papers (Scott et al., 2013; Shaw et al., 2013) that consider all four supplier selection criteria at once (see Table 4).

Contingency analysis shows that there is no significant correlation between the consideration of risks from beyond first tier suppliers with any of our supplier selection dimensions (economic or operational, environmental, social, global risk factors). This means that there is no statistical indication that the consideration of multi-tier suppliers is (positively or negatively) linked to specific types of supplier selection models. Although it may be hypothesized that the integration of risks from the entire supply chain may rather go with the mind-set of global supplier selection models since both approaches have to deal with highly uncertain events that are difficult to grasp and to estimate. A crucial difference between these two approaches may reside in the fact that global supplier selection may concern geographically and often also culturally distanced suppliers with whom, however, direct contractual relationships (and hence potential influence) exist. This is usually not the case with second (and beyond second) tier suppliers.

Table 5. Analysis of correlations between supplier selection dimensions

Category pairs	Expected relative frequency[a]	Observed relative frequency[a]	Exact significance (two-sided) of Fisher's Exact Test	Phi-coefficient (φ)	Approximate significance
Env- Soc	0.29	0.36	.034	.369	.027
Env-Glob	0.16	0.06	.001	-.645	.000

[a]Figures are rounded.

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CONCLUSION AND AGENDA FOR FUTURE RESEARCH

In this chapter, we present a content analysis based literature review on global sustainable supplier selection. Four categories of criteria (or dimensions of supplier selection) are identified namely economic, environmental, social and global. The top three criteria in the economic category being quality, cost and general supplier characteristics, in social category being employees, transparency and engagement, and local communities' influence, in environmental category being pollution and hazardous emissions, standards and management systems, green product and design, and green competencies and processes, and in global category being distance, other risks, and politics and economy.

From contingency analysis, we found that environmental and social dimensions are moderately positively associated whereas a strong negative association exists between environmental and global criteria. This means that models tend to consider environmental and social criteria together in the supplier selection process. In contrast, models combining environmental considerations with global risk factors are rare. Therefore, there is a need for further research that integrates global risk factors and social criteria in the global supplier selection process.

It was also found from our study that no significant correlation exists between the consideration of risks from beyond first tier suppliers with any of the supplier selection dimensions (economic or operational, environmental, social, global risk factors). The absence of any methodological process for evaluating the performance of suppliers beyond the first tier makes the supply chain vulnerable to sustainability risks and increases the overall cost of maintaining supply chain quality. There are currently very few studies that address this critical problem of beyond first tier suppliers at all and even less that suggest a systematic methodological procedure for supplier selection considering various sub-supplier levels. Therefore more studies are required that pay attention to sustainability risks beyond first tier suppliers.

Lastly, majority of studies focus on economic and environmental dimension with quantifiable indicators. Integration of social and global dimension in the global sustainable supplier selection process with mainly qualitative indicators is another challenge that needs to be addressed.

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APPENDIX

Table 6. Full list of economic or operational supplier selection criteria

Cost	Average time interval of price change	Shaw et al. (2013)
	Compliance with cost analysis system	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Compliance with sectoral price behaviour	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Cost of shipment / freight / logistics	Azadi et al. (2014),Büyüközkan (2012),Chan and Kumar(2007),Che (2010),Kannan et al. (2014b), Kannan et al.(2013),Ku et al.(2010),Kuo et al. (2010),Lin et al.(2012),Yeh and Chuang (2011)
	Cost reduction activities	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Expanding market entry and share from supplier's side	Lee (2009)
	Fixed price (or known escalator)	Scott et al.(2013)
	Holding cost	Azadnia et al.(2014)
	Inventory reduction	Lee (2009)
	Low initial price	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Negotiation	Lin et al.(2012)
	Order change and cancellation charges	Ravindran et al.(2010)
	Ordering cost	Azadnia et al.(2014)
	Penalty for delay payment	Shaw et al. (2013)
	Price increasing trend	Shaw et al. (2013)
	Purchase savings	Lee (2009)
	Purchasing cost / price	Azadi et al. (2014),Büyüközkan (2012),Chan and Kumar(2007),Che (2010),Kannan et al. (2014b), Kannan et al.(2013),, Ku et al.(2010),Kumar et al.(2014),Kuo and Lin (2012),Kuo et al. (2010),Lin et al.(2012),Ravindran et al.(2010), Scott et al.(2013), Wittstruck and Teuteberg (2012),Yazdani (2014),Yeh and Chuang (2011)
	Quantity discount	Kannan et al.(2013)
	Reducing repetitive investment	Lee (2009)
	Resource utilization cost	Zhou et al. (2012)
	Take or pay clause conditions	Scott et al.(2013)
	Tariff and taxes	Chan et al.(2008),Chan and Kumar(2007),Ku et al.(2010)
	Trade credit option	Shaw et al. (2013)
	Waste disposal cost	Zhou et al. (2012)
Dependability	Delivery schedule	Azadnia et al.(2014),Büyüközkan (2012),Chan and Kumar(2007),Kannan et al. (2014b),Kuo and Lin (2012)
	Delivery reliability	Azadi et al. (2014),Azadnia et al.(2014) Bai and Sarkis (2010), Dou and Sarkis (2010), Kannan et al. (2014b),Ku et al.(2010),Lee (2009),Ravindran et al.(2010),Zhou et al. (2012)
	Frequency of orders	Kuo et al. (2010)
	Order fulfilment rate	Kannan et al. (2014b), Kannan et al.(2013), Kuo et al. (2010)
Flexibility	Agile manufacturing capability	Zhou et al. (2012)
	Customisation	Kuo and Lin (2012)
	Flexible supply capability, Zhou et al. (2012)	Zhou et al. (2012)
	Number of shipments	Azadi et al. (2014)

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Table 6. Continued

Flexibility (continued)	Prompt response	Bai and Sarkis (2010), Dou and Sarkis (2010) ,Kannan et al. (2014b),Ravindran et al.(2010),Zhou et al. (2012)
	Response to changes	Büyüközkan (2012),Chan and Kumar(2007),Kuo et al. (2010),Ku et al.(2010)
	Response to product mix changes	Kuo and Lin (2012)
	Set-up time	Ku et al.(2010)
	Short set-up time	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Volume flexibility	Bai and Sarkis (2010), Dou and Sarkis (2010), Kuo and Lin (2012)
Innovativeness	Acquisition and security of patents and critical technologies	Lee (2009)
	Capability of Product Development	Kannan et al. (2014b)
	Capability of R&D	Kannan et al.(2013), Kannan et al. (2014b),Lee et al. (2009),Lin et al.(2012),Ravindran et al.(2010)
	Improvement programs	Ravindran et al.(2010)
	(Manufacturing) Process improvement	Kuo and Lin (2012),Kuo et al. (2010)
	New launch of products	Bai and Sarkis (2010), Dou and Sarkis (2010)
	New use of technologies	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Suppliers design capability	Dou and Sarkis (2010), Kannan et al.(2013), Kuo et al. (2010),Lee et al. (2009)
Quality	Capability & commitment of quality management	Kuo et al. (2010),Lee et al. (2009),Shaw et al. (2013)
	Capability of handling abnormal quality	Kannan et al. (2014b),Lee et al. (2009)
	Conformance quality / product quality	Azadnia et al.(2014), Bai and Sarkis (2010),Chan et al.(2008),Dou and Sarkis (2010),Kumar et al.(2014),Kuo and Lin (2012),Lee (2009), Scott et al.(2013),Yeh and Chuang (2011)
	Continuous quality improvement	Shaw et al. (2013)
	Implementation situation of quality control	Kuo and Lin (2012)
	Increased lead time due to quality problems	Büyüközkan (2012),Chan and Kumar(2007)
	Inspection situation of quality control	Kuo and Lin (2012)
	Product reliability	Chan et al.(2008),Lee (2009),Lin et al.(2012)
	Product shipment quality	Shaw et al. (2013)
	Quality assessment/assurance	Büyüközkan (2012),Chan et al.(2008),Chan and Kumar(2007),Kannan et al. (2014b), Kannan et al.(2013), Ku et al.(2010),Kuo and Lin (2012),Kuo et al. (2010)
	Quality control process and mechanisms in place	Scott et al.(2013)
	Quality philosophy	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Quality system	Kannan et al. (2014b),Lee et al.(2011)
	Quality-related certificates (e.g., ISO 9000 and QS 9000)	Lee et al. (2009),Shaw et al. (2013)
	Rejection / defective rate of the product	Büyüközkan (2012),Chan and Kumar(2007),Kannan et al. (2014b), Kannan et al.(2013), Ku et al.(2010),Kuo et al. (2010),Ravindran et al.(2010)
	Remedy for quality problems	Büyüközkan (2012),Chan and Kumar(2007)
	Service quality/capability	Amindoust et al. (2012b),Bai and Sarkis (2010),Büyüközkan and Çifçi(2011),Dou and Sarkis (2010),Kannan et al. (2014b),Shaw et al. (2013)
	Technological and R&D support	Büyüközkan (2012),Chan and Kumar(2007),Ku et al.(2010)

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Table 6. Continued

Quality (continued)	Total Quality Management	Zhou et al. (2012)
	Warranties and claim policies	Kannan et al. (2014b),Shaw et al. (2013)
Relationship	Availability of online ordering and order tracking	Kannan et al. (2014b),Ravindran et al.(2010)
	Communication system	Kumar et al.(2014)
	Company stakeholders' perceptions on the impact of relationship	Lee (2009)
	Conflict resolution	Bai and Sarkis (2010),Dou and Sarkis (2010),Kannan et al. (2014b),Kuo et al. (2010),Lee (2009)
	Cooperation	Kuo and Lin (2012)
	Cooperation risk	Zhou et al. (2012)
	Coordination	Lee (2009)
	Cost of forming the relationship	Lee (2009)
	Ease of communication / communication openness	Büyüközkan (2012),Chan and Kumar(2007),Dou and Sarkis (2010),Ku et al.(2010),Lin et al.(2012)[30]
	Efficient IT-interfaces / Electronic Data Interchange	Büyüközkan (2012),Ku et al.(2010),Ravindran et al.(2010),Wittstruck and Teuteberg (2012)
	Feeling of trust / credibility	Dou and Sarkis (2010),Lee (2009),Levary (2008),Lin et al.(2012)
	Long term contract / relationship	Büyüközkan (2012),Dou and Sarkis (2010)[30]
	Loyalty level	Azadnia et al.(2014)
	Partnership formation time	Bai and Sarkis (2010),Dou and Sarkis (2010)
	Productivity of human resources as a result of the relationship	Lee (2009)
	Protection of client's proprietary information	Levary (2008)
	Relationship closeness	Dou and Sarkis (2010),Shaw et al. (2013)
	Sharing expertise	Kannan et al. (2014b),Lee (2009)
	Sharing of critical information	Kuo et al. (2010),Lee (2009)
	Stabilised relationship	Lee (2009)
	Synergies	Lee (2009)
	Time to forming the relationship	Lee (2009)
Speed	Delivery speed	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Lead-time	Kannan et al. (2014b), Kannan et al.(2013),, Ku et al.(2010),Kumar et al.(2014),Kuo et al. (2010),Ravindran et al.(2010)
	Product development time	Bai and Sarkis (2010),Dou and Sarkis (2010),Kuo et al. (2010)
	Production time	Che (2010),Yeh and Chuang (2011)
	Time from order to delivery	Lee (2009)
	Time-to-market	Lee (2009)
	Transportation time	Che (2010),Yeh and Chuang (2011)
Technology & processes	Assessment of future manufacturing capabilities	Dou and Sarkis (2010)
	Developing technical standards	Lee (2009)
	Joint product/technology development	Lee (2009)
	Process capability	Chan et al.(2008),Ku et al.(2010)
	Production facility and capacity	Amindoust et al. (2012b),Azadi et al. (2014),Chan and Kumar(2007),Dou and Sarkis (2010),Kuo and Lin (2012),Ravindran et al.(2010)

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Table 6. Continued

Technology & processes (continued)	Production risk	Zhou et al. (2012)
	Technology and knowledge transfer	Lee (2009)
	Technology/technological capability / compatibility	Azadi et al. (2014),Büyüközkan and Çifçi(2011),Chan et al.(2008),Dou and Sarkis (2010),Kannan et al. (2014b), Kannan et al.(2013),, Kuo and Lin (2012),Lee (2009),Lee et al. (2009),Lee et al.(2011),Lin et al.(2012)
General supplier characteristics	Access to market	Lee (2009)
	Compatibility among levels and functions	Dou and Sarkis (2010)
	Compatibility of business strategy	Ravindran et al.(2010)
	Credit rating / strength	Kumar et al.(2014), Scott et al.(2013)
	Customer base	Büyüközkan (2012),Chan and Kumar(2007)
	Customer satisfaction	Zhou et al. (2012)
	Financial capability/performance	Amindoust et al. (2012b),Azadi et al. (2014),Büyüközkan and Çifçi(2011),Chan and Kumar(2007),Kumar et al.(2014),Kuo and Lin (2012),Lee et al.(2011),Lin et al.(2012),Ravindran et al.(2010), Scott et al.(2013), Shaw et al. (2013),Wittstruck and Teuteberg (2012)
	Management capabilities	Azadi et al. (2014),Dou and Sarkis (2010),Lee et al.(2011)
	Organization / organizational structure	Amindoust et al. (2012b),Azadi et al. (2014),Büyüközkan and Çifçi(2011),Dou and Sarkis (2010),Kuo and Lin (2012),Lee et al.(2011), Shaw et al. (2013)
	Performance history & past business	Büyüközkan (2012),Chan and Kumar(2007),Kumar et al.(2014),Lee et al.(2011)
	Personnel	Dou and Sarkis (2010)
	Position in industry / market	Kumar et al.(2014)[30]
	Reputation (for integrity)	Büyüközkan (2012),Dou and Sarkis (2010),Shaw et al. (2013)
	Strategic fit	Dou and Sarkis (2010)
	Supplier stock management	Kannan et al. (2014b),Kuo et al. (2010)
	The shelf life or longevity of product supplied	Kumar et al.(2014)
	Top management compatibility	Dou and Sarkis (2010)

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Table 7. Full list of environmental supplier selection criteria

Green communication & information exchange	Carbon emission disclosure and report	Shaw et al. (2013)
	Carbon accounting and inventory	Hashemi et al. (2014)Shaw et al. (2013)
	Information sharing	Beng and Omar(2014)Shaw et al. (2013)
	Inter-functional cooperation for environmental improvement	Kannan et al. (2014a)
	Staff training	Beng and Omar(2014),Yazdani (2014)
	Collaboration	Hashemi et al. (2014)
	Environmental partners	Beng and Omar(2014)
	Life cycle assessment	Arshadi and Mahmoodi(2014)
	Green materials coding and recording	Kannan et al. (2014b)
Green competencies & processes	Ability to alter process and product for reducing the impact on natural resources	Kannan et al. (2014b),Lee et al. (2009)
	Continuous monitoring and regulatory compliance	Kannan et al. (2014b),Lee et al. (2009)
	Internal control process	Kannan et al.(2013), Lee et al. (2009)
	Green / environmental (process) planning	Kannan et al. (2014b), Kannan et al.(2013), Kuo and Lin (2012),Lee et al. (2009)
	Environmental (management) competencies	Amindoust et al. (2012b),Azadi et al. (2014),Büyüközkan (2012),Büyüközkan and Çifçi(2011),Lee et al.(2011),Yazdani (2014)
	Process adaptation	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Identification of environmental aspects	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Planning of environmental objectives	Beng and Omar(2014), Bai and Sarkis (2010), Dou and Sarkis (2010)
	Assignment of environmental responsibility	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Checking and evaluation of environmental activities	Bai and Sarkis (2010), Dou and Sarkis (2010), Kannan et al.(2013)
	Logistics for the environment	Büyüközkan (2012)
	Transportation mode	Büyüközkan (2012)
	Load optimisation	Büyüközkan (2012)
	Geographical location	Büyüközkan (2012)
	Buying /availability of new environmentally friendly technology	Beng and Omar(2014),Kannan et al. (2014a),Kannan et al. (2014b), Zhou et al. (2012)
	Green R&D	Amindoust et al. (2012b),Azadi et al. (2014),Kannan et al. (2014b)
	Carbon risk assessment	Shaw et al. (2013)
	Carbon management (measures, training)	Hashemi et al. (2014)Shaw et al. (2013)
	Process auditing	Kannan et al. (2014b)
Green management of own suppliers	Passing ISO 14000 verification of suppliers	Che (2010),Yeh and Chuang (2011)
	Having environment al protection policies of suppliers	Che (2010),Yeh and Chuang (2011)
	Having environmental protection plans of suppliers	Che (2010),Yeh and Chuang (2011)
	Work with suppliers to meet environmental goals	Kannan et al. (2014a)
	Evaluations of the internal environmental management of suppliers	Kannan et al. (2014a)

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Table 7. Continued

Green management of own suppliers (continued)	Evaluation of the environmental management of 2nd-tier suppliers	Kannan et al. (2014a)
	Green purchasing / supply chain management	Amindoust et al. (2012b), Beng and Omar (2014), Dai and Blackhurst (2012),Kannan et al. (2014a),Kuo and Lin (2012), Lee et al.(2011)
Green product & design	Product stability, low toxicity and durability	Zhou et al. (2012)
	Green product	Azadi et al. (2014),Kannan et al. (2014b),Lee et al. (2009),Lee et al.(2011),Lin et al.(2012),Yazdani (2014),Zhou et al. (2012)
	Green design / design for the environment	Amindoust et al. (2012b), Azadi et al. (2014), Beng and Omar(2014), Büyüközkan (2012), Che (2010), Kannan et al. (2014a), Kannan et al. (2014b), Kannan et al.(2013), Kuo et al. (2010), Lin et al.(2012),Yazdani (2014),Yeh and Chuang (2011)
	Use of harmful material	Kannan et al. (2014a),Lee et al. (2009)
	Green packaging	Kannan et al. (2014a),Kannan et al. (2014b),Lee et al. (2009)
	Product adaptation	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Environment Efficiency	Kannan et al. (2014b)
	Prevention of mixed material (green and non-green materials)	Kannan et al. (2014b)
Pollution & hazardous emissions	Pollution control	Amindoust et al. (2012b), Azadi et al. (2014), Bai and Sarkis (2010), Beng and Omar (2014), Dou and Sarkis (2010), Lee et al. (2009), Lee et al.(2011), Lin et al.(2012)
	Remediation	Bai and Sarkis (2010), Dou and Sarkis (2010)
	End-of-pipe controls	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Production of polluting agents	Bai and Sarkis (2010), Dou and Sarkis (2010), Kannan et al.(2013)
	Production of toxic products	Bai and Sarkis (2010), Dou and Sarkis (2010), Büyüközkan (2012)
	(Cost of) chemical waste	Azadnia et al.(2014),Beng and Omar(2014),Che (2010),Yeh and Chuang (2011)
	Product waste	Azadnia et al.(2014)
	GHG emissions / carbon footprint (methane, CO2, NO20	Azadnia et al.(2014), Dai and Blackhurst (2012), Hashemi et al. (2014), Kumar et al.(2014), Scott et al.(2013), Shaw et al. (2013)
	Waste electrical and electronic equipment	Amindoust et al. (2012b),Kuo et al. (2010)
	Diversion of material from landfill	Scott et al.(2013)
	(Costs of) waste disposal / management	Amindoust et al (2012a), Kannan et al. (2014b), Shaw et al. (2013),Yazdani (2014), Zhou et al. (2012)
	Management for / restriction of Hazardous Substances	Kannan et al. (2014b), Kuo et al. (2010),Yeh and Chuang (2011)
	Ozone depleting chemicals	Amindoust et al. (2012b), Azadi et al. (2014), Kuo et al. (2010)
	Materials used in the supplied components that reduce the impact on natural resources	Beng and Omar(2014), Lee et al. (2009)
	(Costs of) Solid waste	Bai and Sarkis (2010), Dou and Sarkis (2010), Beng and Omar(2014),Che (2010), Kannan et al.(2013), Lee et al. (2009), Shaw et al. (2013),Yeh and Chuang (2011)

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Table 7. Continued

Pollution & hazardous emissions (continued)	(Costs of) Liquid waste	Beng and Omar(2014), Che (2010), Kannan et al.(2013), Lee et al. (2009), Shaw et al. (2013),Yeh and Chuang (2011)
	(Costs of) air emissions (e.g., SO2, NH3, CO and HC1)	Beng and Omar(2014),Che (2010), Kannan et al.(2013), Lee et al. (2009), Shaw et al. (2013),Yeh and Chuang (2011)
Recycling	Quality of recycling processes	Wittstruck and Teuteberg (2012)
	Recycling / reusing / re-manufacturing capability / level	Amindoust et al. (2012b), Beng and Omar(2014), Che (2010), Kannan et al. (2014a), Kannan et al. (2014b), Kannan et al.(2013), Lee et al. (2009), Wittstruck and Teuteberg (2012),Yazdani (2014),Yeh and Chuang (2011)
	Cost of component disposal	Kannan et al. (2014b), Lee et al. (2009), Lee et al.(2011)
	Reverse logistics / returns handling capability	Beng and Omar(2014),Che (2010),Lee et al.(2011),Yeh and Chuang (2011)
Resources	Raw material consumption	Bai and Sarkis (2010), Dou and Sarkis (2010), Kannan et al.(2013)
	Water consumption	Azadi et al. (2014) Bai and Sarkis (2010), Dou and Sarkis (2010), Kannan et al.(2013)
	Energy consumption	Bai and Sarkis (2010), Dou and Sarkis (2010), Amindoust et al. (2012b), Azadi et al. (2014), Beng and Omar(2014), Büyüközkan (2012), Che (2010), Dai and Blackhurst (2012), Kannan et al.(2013), Lee et al. (2009), Lin et al.(2012), Shaw et al. (2013),Yeh and Chuang (2011)
	Renewable energy	Azadi et al. (2014)
	Material efficiency	Dai and Blackhurst (2012)
Standards & management systems	Performance against EU sustainability assurance standards	Scott et al.(2013)
	Number of obtained ISO standards	Azadi et al. (2014)
	Environmental management system (e.g., ISO 14001)	Amindoust et al. (2012b), Azadi et al. (2014), Azadnia et al.(2014), Beng and Omar(2014), Büyüközkan (2012), Kannan et al. (2014a), Kannan et al. (2014b), Kuo et al. (2010), Lee et al. (2009), Shaw et al. (2013),Wittstruck and Teuteberg (2012),Yazdani (2014)
	Compliance with legal environmental requirements and auditing programs	Kannan et al. (2014a)
	Environmental administration system	Kuo and Lin (2012)
	FSC accreditation	Scott et al.(2013)
	Establishment of environmental commitment and policy	Bai and Sarkis (2010), Dou and Sarkis (2010), Beng and Omar(2014), Kannan et al. (2014b), Kannan et al.(2013)
General green risks	Green risk	Zhou et al. (2012)
	Environmental costs	Amindoust et al. (2012b), Azadi et al. (2014), Büyüközkan (2012)
	Social responsibility (of the supplier towards environment protection)	Lee et al. (2009), Lin et al.(2012)
	Ratio of green customers to total customers	Kannan et al. (2014b), Lee et al. (2009)
	Environmental protection level	Azadnia et al.(2014)
	Green image	Beng and Omar(2014), Che (2010), Kannan et al. (2014b), Lee et al.(2011),Yeh and Chuang (2011)
	Biodiversity change	Amindoust et al (2012a), Scott et al.(2013)
	Land use change	Scott et al.(2013)

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Table 7. Continued

General green risks (continued)	Environmental regulatory environment within which the supplier operates	Kannan et al. (2014b), Scott et al.(2013)
	Senior management support	Beng and Omar(2014)
	Green customer's purchasing retention	Arshadi and Mahmoodi(2014), Beng and Omar(2014),Yeh and Chuang (2011)
	Green market share	Arshadi and Mahmoodi(2014), Beng and Omar(2014)
	Stakeholder relationship	Beng and Omar(2014), Kannan et al. (2014b)
	Annual growth in green products	Arshadi and Mahmoodi(2014)
	Green customers acquisition	Arshadi and Mahmoodi(2014)
	Recycling cost	Lee et al.(2011)
	Employment practices	Lee et al.(2011)

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Table 8. Full list of social supplier selection criteria

Employees	Work safety and labour health (management)	Amindoust et al. (2012b),Azadi et al. (2014),Azadnia et al.(2014), Bai and Sarkis (2010), Dou and Sarkis (2010), Wittstruck and Teuteberg (2012)
	Interests and rights of employees	Amindoust et al. (2012b),Azadi et al. (2014),Kannan et al. (2014b),Kuo et al. (2010)Shaw et al. (2013)
	Disciplinary and security practices	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Employee contracts	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Equity labour sources	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Diversity	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Discrimination	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Flexible working arrangements	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Job opportunities / creation	Azadnia et al.(2014),Dai and Blackhurst (2012)[30] Bai and Sarkis (2010), Dou and Sarkis (2010)
	Employment compensation	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Research and development	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Career development	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Training	Azadnia et al.(2014)
	Small and medium enterprise (SME) employment created	Scott et al.(2013)
	Child labour	Shaw et al. (2013),
Local communities influence	Health	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Education	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Housing	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Service infrastructure	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Mobility infrastructure	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Regulatory and public services	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Supporting educational institutions	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Sensory stimuli	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Security	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Cultural properties	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Economic welfare and growth	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Social cohesion	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Social pathologies	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Grants and donations	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Supporting community projects	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Social/ Humane Capital	Amindoust et al (2012a)
Standards	Performance against EU sustainability assurance standards	Scott et al.(2013)
	Partnership screens and standard	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Procurement standards	Bai and Sarkis (2010), Dou and Sarkis (2010)
	FSC accreditation	Scott et al.(2013)

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Table 8. Continued

Transparency & engagement	Information disclosure	Amindoust et al. (2012b),Azadi et al. (2014), Kannan et al. (2014b), Kuo et al. (2010)
	Consumers education	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Stakeholder empowerment	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Stakeholder engagement	Bai and Sarkis (2010), Dou and Sarkis (2010)
	Rights of stakeholders (shareholders, consumers, communities, etc.)	Amindoust et al. (2012b),Kannan et al. (2014b),Kuo et al. (2010), Shaw et al. (2013)
General social issues	Sustainable image	Wittstruck and Teuteberg (2012)
	Social responsibility	Büyüközkan and Çifçi(2011)

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Table 9. Full list of global supplier selection criteria

Culture & language	Cultural and communication barriers	Lee et al.(2011)
	Cultural similarity/differences	Büyüközkan (2012), Ku et al.(2010),Lee (2009)
	Language	Ku et al.(2010)
Distance	Geographical location	Chan et al.(2008),Chan and Kumar(2007),Ku et al.(2010),Scott et al.(2013)
	Reliability of logistics providers	Levary (2008),Tse and Tan (2011)
	Difficulty in cross-functional and cross location coordination	Shaw et al. (2013)
	Longer lead time	Shaw et al. (2013)
	Number of transition in transportation	Tse and Tan (2011)
Politics & economy	Political stability/risk	Chan and Kumar(2007),Chan et al.(2008), Levary (2008), Shaw et al. (2013),Ku et al.(2010)
	Economy	Chan et al.(2008),Chan and Kumar(2007), Ku et al.(2010)
	Terrorism	Chan et al.(2008),Chan and Kumar(2007), Shaw et al. (2013)
	Foreign policies	Chan et al.(2008)
	Exchange rates	Chan et al.(2008), Ku et al.(2010), Levary (2008), Shaw et al. (2013)
	Crime rate	Chan et al.(2008)
	Risk due to natural or man caused disaster	Ku et al.(2010), Levary (2008)
	Legal difficulties	Shaw et al. (2013)
	Trade barriers / facilitators	Ku et al.(2010)
Other global risks	Risk due to supply disruption	Ravindran et al.(2010)
	Visibility of supply chain	Lee (2009)
	Traceability (chain of custody)	Scott et al.(2013)
	Dependency on imports	Scott et al.(2013)
	Reliability of the supplier's suppliers	Levary (2008)
	Quality, reliability and safety of product	Tse and Tan (2011)
	Product quality risk visibility	Tse and Tan (2011)

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Chapter 2
An Integrated AHP–QFD–Based Compromise Ranking Model for Sustainable Supplier Selection

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ABSTRACT

Sustainability in industrial organizations has become a predominant concept in the 21st century due to environmental regulations, economic importance, and social obligations. In this context, sustainable supplier selection plays an epochal role for taking strategic business decisions. So, a systematic approach is required to deal with the sustainable factors. By integrating the three pillars of sustainability, namely economic, environmental, and social factors, this chapter presents an integrated model for supplier selection from a sustainability perspective. The proposed framework combines analytic hierarchy process (AHP) and quality function deployment (QFD) methods to deal with the sustainable criteria. Finally, suppliers are ranked using VIse Kriterijumska Optimizacija kompromisno Resenja (VIKOR) method. The proposed framework is used to analyze a case study of a dairy company, but it can also be implemented for sustainable supplier selection in any industries. The study brings an artefact for managers to effectively analyze suppliers with the integrated decision-making model.

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INTRODUCTION

The management of social and environmental issues and the necessity to address them in parallel with the economic factors represents nowadays a top priority for managers and decision makers (DMs) in many sectors such as manufacturing, business development, tourism and agriculture (Amindoust et al. 2012). Such a synthesis of economic, environmental and social development is generally referred to as sustainable development or sustainability (Gauthier 2005; Dai and Blackhurst 2012). Sustainability in a supply chain management (SCM) applies to all relevant SC aspects: product design, material purchasing, manufacturing processes, final product delivery and reusing/ recycling design (Sarkis 2006; Srivastava 2007; Lin and Ho 2011). Managers' objective in sustainable SCM (SSCM) is the improvement of the economic condition of their organization focusing on what is needed not only to survive but also to prosper both in the near and the distant future. SSCM requires the managers to undertake social and environmental responsibility that can improve the economic performance (Carter and Liane Easton 2011; Sancha et al. 2015). In addition, supply chain managers must be aware of the environmental concerns and social aspects which are affected, by the choices they make in terms of supplier selection and supplier development, modal and carrier selection, vehicle routing, location and packaging. To select a network of sustainable suppliers is fundamental when designing new development and marketing strategies and more flexible models for the long-term policies of the organization (Dotoli and Falagario 2012; Pitchipoo et al. 2013), while it is essential when only limited resources are available (Carter and Liane Easton 2011). Therefore, one of the main questions in SSCM is to configure and implement an effective supplier selection process (Bayrak et al. 2007; Punniyamoorthy et al. 2011). Sustainable supplier selection problems (SSSPs) can be explained as classical supplier selection problems (SSPs) incorporating environmental and social factors to evaluate and rank the suppliers' performance in order for the managers to choose the optimal suppliers (Genovese et al. 2010). The problem is then to define a method flexible enough to allow for an overall evaluation as comprehensive and objective as possible of all the available suppliers. In this way, it is essential to run a systematic analysis of the interdependencies existing among the customer requirements (CRs) and the way they influence the technical requirements (TRs). However, from the theoretical background and managerial attitude this kind of analysis remains overlooked as a research gap that affects decision-making and long-run development planning.

Over the years, there has been an increasing attention in the number of studies combining several techniques for assessing suppliers' performance (Labib 2011; Zhang et al. 2012). Many contributions to sustainable supplier selection (SSS) have been obtained by employing multi-criteria decision-making (MCDM) tools (see, among others, Bottani and Rizzi 2008; Chen and Wang 2009; Awasthi et al. 2010; Amindoust et al. 2012). However, developing decision-making approaches to SSS through integrated methods can be very substantial since the single methods involve specific functions that provide stable solutions only if suitably combined together. Thus, the fuzzy decision approaches applied in the literature on green supplier selection mostly consist of fuzzy-integrated single model approaches (Govindan et al. 2015). In order to provide a meaningful and practical solution to SSSPs, this chapter proposes an integration of different MCDM tools, namely, analytic hierarchy process (AHP), quality function deployment (QFD), VIse Kriterijumska Optimizacija kompromisno Resenja (VIKOR) methods. Supplier selection problem is subordinated to both determining the degree of importance (weight) of the selection criteria and evaluating the suppliers with respect to these criteria (Ordoobadi 2009; Amindoust et al. 2012). In this study, these goals are achieved through an integrated MCDM model. The sustainable factors/criteria are defined based on the available literature. The main factors are interpreted as CRs and used to identify

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the TRs. AHP and QFD are integrated to determine the weights of all the criteria introduced. Again, AHP is used to weight all suppliers with respect to each TR. Then VIKOR method is used to rank all the candidate suppliers. Finally, we perform some comparison to test the validity and consistency of the rankings obtained. From the technical viewpoint, the main contribution of the proposed approach is in the way it combines AHP and QFD. One of the essential tasks in MCDM modelling is seeking new and logical ways to weight decision factors (attributes). Mainly, fuzzy linguistic variables, AHP, analytic network process (ANP), and entropy are employed to determine the weights of all the factors. However, in many decision problems the importance of the decision criteria is dictated by the stakeholders' satisfaction and customers' preferences. The AHP-QFD phase of the proposed method provides a simple to implement customer dependent weighting method for the decision criteria.

The proposed framework is used to analyze a case study of a dairy company, but it can be easily implemented to solve SSSPs by any other company with similar features. However, the questionnaires and procedures should be adapted to the specific case in order to avoid opportunity costs in terms of efficiency losses and foregone profits deriving from the selection of less than efficient suppliers.

The remainder of this section is organized as follows: Section 3 provides a literature review on the MCDM methods used in the last decades in SCM to address SSSPs and identify the sustainable factors. Section 4 illustrates the research objectives and questions and introduces the proposed five phase integrated method. Section 5 shows the results obtained for the case study under analysis. Finally, Section 6 draws the conclusions and presents the limitations of the proposed method.

LITERATURE REVIEW

The existing literature on sustainable development of suppliers covers both theoretical/analytical analyses. MCDM techniques, such as AHP, ANP, QFD and technique for order of preference by similarity to ideal solution (TOPSIS), often merged with a fuzzy approach, have been extensively considered in many SSSPs. TOPSIS and VIKOR (Hwang and Yoon 1981) are both practical and useful techniques that allow experts to choose the desired alternatives based on their distances from the ideal and the negative ideal solutions. Awasthi et al. (2010) and Govindan et al. (2013) validated a fuzzy TOPSIS structure to list the best supplier under environmental variables. In particular, Awasthi et al. (2010) used fuzzy decision making using TOPSIS and VIKOR to evaluate suppliers' environmental performance on the basis of decision criteria such as the usage of environmentally friendly technology, the employment of environmentally friendly materials, the management commitment to green practices and the pollution control initiatives. Erol et al. (2011) proposed a multi-criteria framework based on fuzzy entropy and fuzzy multi-attribute utility (FMAUT) to evaluate sustainable suppliers' performance in a supply chain. Wen et al. (2013) proposed a fuzzy intuitionistic TOPSIS model for SSS in a group decision environment. Orji and Wei (2014) used Fuzzy logic, Decision-making Trial and Evaluation Laboratory (DEMATEL) and VIKOR to analyze sustainability criteria and select the best sustainable supplier. Shen et al. (2013) presented a fuzzy-based TOPSIS method for green supplier's performance in green supply chain. Proposed method was investigated for a real-life case study of an auto industry. Kannan et al. (2014) used triangular fuzzy numbers for TOPSIS method. Fuzzy TOPSIS was used for supplier selection problem in a green supply chain of an electronics company. Rostamzadeh et al. (2015) utilized VIKOR method under fuzzy environment using triangular numbers for a green supply chain problem. Luthra et al. (2017) proposed an integrated decision making structure using AHP and VIKOR in order to address supplier selection

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problem considering sustainability. They evaluate their model for a case study of automobile industry in India. Zhang and Xing (2017) used VIKOR method in order to address green supplier selection problem.

AHP is a well-known technique used in MCDM to identify and analyze the hierarchy of the decision factors of a decision problem (Saaty 1980, 1986). ANP is a generalized form of AHP enabling DMs to define and study the functional interdependency existing among the decision factors belonging both to different levels of a hierarchy and to the same level. (Saaty 1996).

Lee et al. (2009) provided the first attempts to bridge the gap between the abundant research existing on supplier selection and the rather limited one concerning environmental issues. The paper proposed a green supplier selection model using AHP within a fuzzy approach. More in general, fuzzy AHP, fuzzy ANP and fuzzy multi-objective programming tools have been widely used to determine SSS strategies to apply to case studies of several industries (Shaw et al. 2012; Azadnia et al. 2013, 2015; Kannan et al. 2013. QFD is a structured and engineering customer-driven product design approach whose basic task is to translate CRs into TRs (Akao and King 1990; Bevilacqua et al. 2006; Zhang and Chu 2011). Introduced by YojiAkao in the 1960s and first used in 1972 at Mitsubishi industries, QFD approach has been attentively considered in Japanese and American companies to improve product design and development (Luo et al. 2008; Li et al. 2010). Ho et al. (2012) used a QFD-based approach to translate the company stakeholder requirements into multiple criteria for supplier selection. Dursun and Karsak (2013) developed a Family Group Decision Making approach using QFD. The proposed methodology initially identified the features that a product must possess to meet the customer needs (CNs) and then established the relevant supplier assessment criteria. Asadabadi (2014) presented a hybrid QFD-based approach where the best supplier was selected considering the changes in CNs and the priorities derived from the product requirements (PRs). Tavana et al. (2017) introduced ANP-QFD decision making structure for SSP under sustainability criteria. Yazdani et al. (2017) proposed an integrated framework including QFD-DEMATEL-COPRAS for green supplier selection problem. They investigated the proposed method for a real case study in diary company. In another study, Yazdani et al. (2017) integrated QFD and TOPSIS methods for supplier selection problem with an application in logistics provider. As same as Yazdani et al. (2017), Van et al. (2018) introduced a new framework using QFD and TOPSIS methods for green supplier selection problem. Babbar and Amin (2018) used QFD and multi objective linear programming for supplier selection problem in green supply chain with a focus on environmental aspects. They performed the proposed method for a beverage industry. Best-Worst method and VIKOR method were integrated as a tool in a study by Garg and Sharma (2018) for SSP. They tested the tool for an electronics industry.

i. INTEGRATED AND INTELLIGENT APPROACHES TO SSSPs

All the aforementioned methods have been widely used for multi-factor analysis and applied to supplier selection. They are relatively easy to use, flexible and logically consistent. However, in order to be successfully implemented, they also require some specific assumptions to be satisfied. For instance, AHP relies on the possibility of defining a common hierarchical structure for factors and decision criteria. The integration of different MCDM tools allows overcoming the inadequacy of the individual methods to deal with real-world limitations such as processing capacity, incomplete information and fuzzy evaluations. In particular, combining AHP with other methods usually offers a systematic and easy-to-implement approach to SSPs. See, among others, Cebi and Bayraktar (2003), Ghodsypour and

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O'Brien (1998), Wang et al. (2004, 2005). Fallahpour et al. (2017) introduced a new tool which was built using AHP, preference programming and TOPSIS methods for SSPs. Azimifard et al. (2018) used an integrated decision making approach based on AHP and TOPSIS for SSP for a case study in steel company. Abdel-Baset et al. (2019) integrated ANP and VIKOR methods for SSP using sustainability criteria. They implemented Neutrosophic sets for the proposed tool. This method was evaluated for an importing company. An integrated tool using AHP and VIKOR was proposed by Awasthi et al. (2018) for SSP. Several integrated models have been investigated to optimize supplier selection processes. The most recent studies have focused on integrated analytic frameworks combining:

- AHP with QFD (Choy et al. 2004; Bhattacharya et al. 2010; Amin et al. 2011; Rajesh and Malliga 2013; Taghizadeh and Ershadi 2013; Dey et al. 2015);
- DEMATL, fuzzy ANP and fuzzy TOPSIS (Bayrak et al. 2007);
- QFD and TOPSIS (Kumaraswamy et al. 2011; Van et al. 2018; Yazdani et al. 2017).
- AHP and VIKOR (Luthra et al. 2017; Awasthi et al. 2018)
- AHP and TOPSIS (Fallahpour et al. 2017; Liu et al. 2019)

In this chapter, the importance of the TRs (i.e. decision criteria) is assumed to be dependent on the CRs, that is, the weights assigned to the CRs influence those assigned to the TRs. In real-life situations, the weights of the TRs are assigned considering a series of technical difficulties and target values that can be too complex to be analyzed using an AHP comparison matrix. In other words, it may be too restrictive to structure the CRs and TRs using a common hierarchy. It follows our choice of integrating AHP with QFD. In the proposed integrated framework, AHP is used to weight only the CRs. The weights of the TRs are assigned afterwards so as to reflect the importance of the CRs and account for the issues relevant to stakeholders and customers' satisfaction. Once the TRs are weighted, it is necessary to rank the suppliers. AHP can be applied to weight each supplier with respect to each decision criterion, but then one or more MCDM tools are needed to evaluate the overall performance of the suppliers and validate the ranking process. We will use VIKOR since it is based on a comparison matrix that can be derived from AHP and are not complex from the computational viewpoint. However, other MCDM tools could be implemented without changing the main objective of this chapter.

ii. SUSTAINABLE SUPPLIER SELECTION VARIABLES

In the literature, there are many studies aiming at identifying the principal criteria for sustainable supplier evaluation. The traditional supplier selection approaches have considered economic attributes and factors like cost (Punniyamoorthy et al. 2011), quality (Kuo et al. 2010; Mafakheri et al. 2011), flexibility (Humphreys et al. 2006; Lu et al. 2007; Büyüközkan 2012) and technology capability (Lu et al. 2007; Kuo et al. 2010; Zhu et al. 2010; Mafakheri et al. 2011) in their supplier evaluation policy. Environmental and social factors in the sustainable approach to supplier evaluation must be supposed in order to measure the suppliers' performance effects on all the stages of the supply chain. The essential environmental and social factors usually include social responsibility (Hirsch et al. 1998; De Brito et al. 2008; Tsai and Hung 2009; Büyüközkan 2012), cleaner/environmental production and technologies (Tsoulfas and Pappis 2006; Matos and Hall 2007; Lu et al. 2007) and environmental management systems (Simpson and Power 2005; Verghese and Lewis 2007; Azadnia et al. 2015). Environmental criteria such as pollution

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production, resource consumption, eco-design and environmental management competency have been addressed by Kannan et al. (2013). Recently, Govindan et al. (2013) and Azadnia et al. (2013) organized sustainable supplier selection studies on employment practices, health and safety, local community influences, and contractual stakeholders, highlighting the influence of social criteria and economic factors on suppliers' performance. Bhattacharya et al. (2014) suggested organizational commitment, eco-design, and green-SC processes as the leading criteria and social and sustainable performances as the lagging ones. They articulated each criterion in sub-criteria and sub-criteria collected form the literature. Bhattacharya, Dey, and Ho (2015) provided a review of the recent research developments highlighting the critical aspects of choosing green/sustainable factors in supply chain design.

Vast amount of studies investigated the green performance measurement and supplier selection (Björklund et al. 2012) while they usually stand on standard performance measurement approaches overlooking the need for a specific analysis of the sustainable development elements (Cuthbertson and Piotrowicz 2008). This generates a considerable gap in the literature. Particularly, when the literature on supplier selection has experienced a significant growth, the one concerning specific environmental issues is rather limited and generally regarded as part of the former. To bridge this gap, a systematic analysis of the links between green constructs and sub-constructs of SCM and all the inter-organizational elements contributing to the performance measurement is very demanding (Bhattacharya et al. 2014). In addition, even though many projects emphasize the influence of CRs and decision criteria on the supplier selection process, to the best of our knowledge, none of them came up with a unique format for evaluation of how these variables influence each other. This proposed integrated framework aims at bridging both gaps highlighted above by providing a systematic analysis of the interdependencies existing among customer variables and technical decision criteria. The analysis allows not only to identify a clear hierarchical structure for all the relevant sustainable factors and sub-factors, but also to weight the decision criteria so as to reflect the importance of the CRs.

PROPOSED FRAMEWORK

The proposed SSSPs comprise the following main tasks: (1) fixing the sustainability factors (CRs and TRs) relevant to supplier selection, (2) analyzing the interdependencies among these factors, (3) determining a method to evaluate the overall performance of the suppliers and, finally, (4) ranking the suppliers to select the bestones in terms of performance. We propose an integrated framework consisting of five phases:

Phase One: Identifying all relevant sustainable factors. In this phase, the relevant sustainable factors/criteria are selected considering the cited literature and the specific features of the company of the case under analysis. Experts from the company are consulted in order to gather information and data and identify both CRs and TRs.

The CRs are the customer variables, that is, the criteria on which the customers will base their choice. The CRs are divided in three main clusters: economic, environmental and social factors. Each cluster consists of several sub-factors / sub-criteria. These criteria are the WHATs in QFD.

The TRs include all the criteria to rank the candidate suppliers, that is, all the criteria that must be considered for the CRs to be satisfied. The TRs are the HOWs in QFD.

Phase Two: Weighting customer and technical requirements

This phase consists of two sub-phases:

Phase Two. One: The CRs are assigned a global weight using AHP.

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Table 1. The ratio scale and definition of AHP

Intensity of importance	Definition
1	Equally important
3	Moderately important
5	Strongly more important
7	Very strong important
9	Extremely more important
2,4,6,8	Intermediate more important
Saaty (1971)	

The AHP is recognized to determine the importance of each decision factor and rank each alternative at the same time. Fundamental rule of AHP is that it acts based on decision experts judgment and pairwise comparison. AHP methodology follows the steps below to find relative importance degree of criteria:

Step 1: Prepare the pair wise comparison matrix A by utilizing the ratio scale in Table 1.

Step 2: Let $C_1,C_2,\ldots,C_n$ as the set of elements, although a_{ij} presents a quantified judgment on pair of elements C_i,C_j the matrix A as below;

$$A=\left[a_{ij}\right]=\begin{bmatrix} 1 & a_{12} & \ldots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \ldots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \ldots & 1 \end{bmatrix} \quad (1)$$

where, a_{ij}=1 and $a_{ji}=\frac{1}{a_{ij}}, i.j=1,2,\ldots,n$

In matrix A, the problem is on determining a set of numerical weights $W_1,W_2,\ldots,W_n$ in front of n element $C_1,C_2,\ldots,C_n$. If A is a consistency matrix, then the relation between weights and judgments are given by $a_{ij}=\frac{W_j}{W_i}$, for (i,j=1,2,3,…,n). The largest Eigen-value λ_{max} would be suggested by Saaty (1971) as;

$$\lambda_{\max}=\sum_{j=1}^{n} a_{ij}\frac{W_j}{W_i} \quad (2)$$

If A is a consistency matrix, then eigenvector X can be obtained by

$$(A-\lambda_{max}I)X=0 \quad (3)$$

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Table 2. Consistency index for AHP process

N	2	3	4	5	6	7	8
R.I.	0.00	0.52	0.9	1.12	1.24	1.32	1.41

So, the consistency index (C.I.) and random index (R.I.) verify the consistency ratio (C.R.). The consistency index and consistency rate are as indicated;

$$C.I. = \frac{\lambda_{\max} - n}{n-1} \tag{4}$$

and

$$C.R. = \frac{C.I}{R.I} \tag{5}$$

The number 0.1 is the accepted upper limit of C.R. If the final consistency ration is higher this value, the evaluation process should be done again to improve consistency.

Phase Two. Two: The weights of the CRs are used in QFD to weight the TRs.

QFD model transforms a matrix, known as house of quality (HoQ) into comparable and measurable units. This matrix expresses the relationship between the CRs (WHATs) and the TRs (HOWs) (Tang et al., 2005) incorporating the following items: A) WHATs matrix, B) HOWs matrix, C) relationship matrix between the WHATs and HOWs, D) relative importance of the WHATs, E) interrelationship between the HOWs, and F) weights of the HOWs. A general representation of a HoQ is shown in Figure 2.

In the first sub-phase, a questionnaire is conducted by the experts of the purchasing department to collect the data that will be used to compose the comparison matrices of ANP and determine the global weights of all the CRs. The ANP pairwise comparisons are carried out using the 1-9 scale reported in Table 1. In the second sub-phase, another questionnaire is conducted to construct the HoQ matrix. The reciprocal influence between the CRs and the TRs is evaluated using a 1,3,6, and 9 scale. This scale is reported in Table 2.

Phase Three: Ranking the suppliers per each technical requirement

To obtain a performance rating of suppliers, in this phase, a questionnaire is conducted by experts of the purchasing department to determine the performance rating of the candidate suppliers. That matrix plus weights of QFD are two inputs for VIKOR method. The data collected using these questionnaires are used for the comparison matrices of AHP relative to each TR. The questions aim at establishing how much a supplier is preferred to the others with respect to each decision criterion (TR). Thus, a vector of local weights (a ranking) for the candidate suppliers is produced for each TR. The AHP pairwise comparisons are carried out using again the 1-9 scale reported in Table 1.

Phase Four: Ranking the suppliers with VIKOR

In this phase, VIKOR ranks the candidate suppliers. To implement these methods, both the weights of the TRs from Phase II and the supplier rankings (one per each TR) obtained in Phase III are needed.

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For the sake of completeness, recall that the solution process VIKOR starts with a $t \times n$ matrix whose generic element is the performance rating of the k-th supplier (k=1,…,t) with respect to the j-th decision criterion (j=1,…,n). The elements of this matrix are then normalized and used to calculate the total performance index of each supplier. The two methods differ in the normalization procedure and in the evaluation of the total performance index.

VIKOR tool: The VIKOR method developed to determine compromise ranking of the decision alternatives with non-commensurable and conflicting criteria and particular weights stability intervals to make adjustments between preference stability and given weights (Opricovic and Tzeng, 2004; Yazdani and Payam, 2015). The specific structure of VIKOR introduces it as an applied tool which is used when decision experts are not be able to explain their preferences in the process of system design. In VIKOR each alternative is measured based on an aggregate function, so the compromise ranking of alternatives is implemented by comparing the measure of closeness to the ideal solution. Any exclusion or inclusion of an alternative could influence VIKOR ranking results. The VIKOR algorithm prepares a minimum of individual regret and maximum group utility for opponent and majority, respectively. One of the characteristics of VIKOR is that always aggregate function is closest to the best solutions. The mathematical computations of VIKOR algorithm are explained in the following steps:

Step 1: Normalize the decision matrix. The process of normalization is done by assuming numerical alternatives j on each criterion i.

$$f_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{m} x_{ij}^2}}, j=1,2,\ldots,m,\ i=1,2,\ldots,n \tag{6}$$

Step 2: Determine the best f_i^* and the worst f_i^- values of all criterion functions, i=1,2,…,n

$$f_i^* = \begin{Bmatrix} \max\limits_i f_{ij} & \text{for benefit criterion} \\ \min\limits_i f_{ij} & \text{for cost criterion} \end{Bmatrix}, j=1,2,\ldots,m \tag{7}$$

$$f_i^- = \begin{Bmatrix} \min\limits_i f_{ij} & \text{for benefit criterion} \\ \max\limits_i f_{ij} & \text{for cost criterion} \end{Bmatrix}, j=1,2,\ldots,m \tag{8}$$

where J is the number of alternative, n is the number of criteria and f_{ij} is the rating of i^{th} criterion function for alternative a_j.

Step 3: Calculate the utility and the regret measure using the following values for alternatives j=1,2,…,m;

$$S_j = \sum_{i=1}^{n} \left[\frac{w_i(f_i^* - f_{ij})}{(f_i^* - f_i^-)}\right] \tag{9}$$

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$$R_j = \max_i [\frac{w_i(f_i^* - f_{ij})}{(f_i^* - f_i^-)}] \tag{10}$$

where w_i is the weight of i^{th} criteria, S_j and R_j are used to formulate ranking measure.

Step 4: Compute the values of Q_j by the following formula;

$$Q_j = \frac{v(S_j - S^*)}{(S^- - S^*)} + \frac{(1-v)(R_j - R^*)}{(R^- - R^*)} \tag{11}$$

$$S^* = \min_j S_j,\ S^- = \max_j S_j,\ R^* = \min_j R_j,\ R^- = \max_j R_j$$

where the solution obtained by S^* belongs to a maximum group utility, the solution obtained by R^* belongs to a minimum individual regret of the opponent and v is considered as the weight of the strategy of the majority of criteria (or "the maximum group utility"). The value of v lies in the range of 0-1. Normally, the value of v is considered as 0.5. The compromise final solution can be investigated and then selected with "voting by majority" (v>0.5), with "consensus" (v=0.5) and with "veto" (v<0.5). To evaluate VIKOR stability it is helpful to arrange ranking orders according to the three different values of v. When v is 0.1, 0.5 and 0.9 and ranking results are very close to each other (depends on correlations), stability and validity of VIKOR are proved.

Step 5: Determine the ranking order of alternatives by Q^* values (ranking index) in decreasing order for a given v.

Phase Five: Validation of results

COPRAS is applied to rank the suppliers. The resulting ranking is used to verify and validate those obtained in Phase IV. In MCDM problems, it is customary to compare the results obtained by two methods using a third method as a "mediator". In this study we use the COPRAS method due to its capability in managing complex decision systems. Developed by Zavadskas et al. (2007), this method has the ability of accounting for both positive (beneficial) and negative (non-beneficial) criteria, which can be assessed independently within the evaluation process. The most important feature of COPRAS is that it estimates the utility of alternatives indicating the extent to which one alternative is better or worse than the other ones.

IMPLEMENTATION, RESULTS, AND ANALYSIS

Even though the proposed procedure may seem long to implement and time-consuming, it has several desirable characteristics:

1. It is not difficult to implement and it does not require much computational effort since it can be put into practice using any common spreadsheet software such as Excel.
2. It is based on a clear distinction between CRs and TRs interpreting them as independent and dependent sustainable variables, respectively. (Phase Two).

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3. The weights of CRs and TRs are assigned so as to systematically reflect stakeholders' wishes while respecting experts' opinions and criteria (Phase Two).
4. It provides three parallel supplier rankings (Phases Three - Five) each of which can be used to control and validate the others and assure the stability of the solutions.

Thus, the proposed five-phase procedure provides an approach to SSSPs which may be time-consuming in the short term but is surely time-saving in the long term. In fact, the five-phase integrated design reduces the subjectivity intrinsic to the supplier assessment process enhancing the quality of managers' choices in view of future policies.

In this section, we show the results obtained by applying the proposed framework to a real SSSP.

The proposed method has been studied to Kalleh dairy company. This is a very large and famous dairy company with years of experience in diverse types of dairy, meat, and beverage and food products in Iran. Kalleh dairy products include UHT processed milk, yoghurt, cheese, dairy drinks, industrial dry milk, industrial powders, buttermilk and desserts for various types of products. The procurement and logistics department called POLE, is in charge of providing a wide range of raw materials of the desired quality at the lowest possible prices. Furthermore, POLE is responsible for purchasing the entire equipment required for the company, including machinery, spare parts, technical parts, laboratory equipment and material-handling equipment.

In particular, POLE plays a key role in the procurement of raw milk which is a strategic raw material in the dairy industry. The company is one of the greatest industrial consumers of raw milk in Iran. In addition, POLE supplies raw material, packaging materials and production technology and process. In order to be competitive and to improve productivity and efficacy, POLE must assess suppliers and their sustainability. Therefore, developing a system to evaluate and identify the top suppliers is an important component of this company's objectives.

In POLE, we consulted the chief executive manager and were introduced the experts to help us to collect the information required for this study. Ten suppliers were considered for the implementation of the method. In the following, the suppliers are denoted by $A_1, \ldots, A_{10}$

Phase One: Based on a literature review and the judgments shared by the experts, we identified the customer indicators (i.e. CRs) and the decision criteria (i.e. TRs) relevant to the case study. This completed Phase One. The factors and sub-factors identified as the customer variables of the case analysis and their hierarchical structure are displayed in Figure 3 together with the decision criteria.

To implement Phases Two and Three, three questionnaires were conducted by three anonymous experts of the purchasing department.

Phase Two. One: One questionnaire was used to gather information on how the customer factors and sub-factors influence each other and interrelate so as to be able to apply AHP and weight the CRs. The experts' judgments were translated into numerical values using the 1-9 scale of Table 1. In this chapter, AHP model with consideration of factors and sub-factors has been presented. So, a multi-level hierarchical model was proposed. The list of factors and sub-factors to satisfy customer and support their requirements in the decision process as well are observed in this Table 3. Finally, the global weights for the customer sub-factors were achieved using the interdependent weights of the factors and the local weights of the sub-factors. The global weight of each sub-factor is obtained by multiplying its local weight by the interdependent weight of the factor to which it belongs.

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Table 3. AHP computation for obtaining weights of CRs

Factors local weight	Sub-factors (Indicators)	Local weight	Global weight
Economic (**0.365**)	Negotiable price (C_{11})	0.188	0.0688
	Product safety (C_{12})	0.292	0.1068
	Durable product (C_{13})	0.267	0.0974
	Availability & accessibility (C_{14})	0.253	0.0922
Environmental (**0.369**)	Environmental commitment (C_{21})	0.368	**0.1359**
	User friendly and environmental adoptability (C_{22})	0.288	0.1064
	Recyclable product (C_{23})	0.161	0.0595
	Degree of hazardous material (C_{24})	0.182	0.0671
Social factor (**0.266**)	Social responsibility (C_{31})	0.220	0.0584
	Energy efficiency (C_{32})	0.149	0.0395
	Ethical and legal issues (C_{33})	0.202	0.0538
	Commitment to employees security (C_{34})	0.429	**0.1142**

In particular, environmental and economic factors resulted to be the most significant and important factors when evaluating the CRs. Moreover, a significant difference can be noticed between the local weights of factors in Table 3. Among global weights of sub factors, the environmental commitment and employee safety commit achieved the biggest importance with 0.1359 and 0.1142, respectively. It announces the comparison matrices and local weights of the sub-factors within their corresponding cluster.

Phase Two. Two: A second questionnaire was conducted to construct the HoQ matrix to use for the QFD process. Through this questionnaire, decision experts used their knowledge of the suppliers to address questions on how CRs and supplier evaluation criteria interact and influence each other. Then through the QFD process, the rating can be realized by these values, (1); Weak relationship, (3); Moderate relationship, (6); strong relationship and finally (9) which stand for very strong relationship. Table 4 shows QFD computation regarding relationship between customer factors and decision criteria for supplier evaluation. The degree of relative impact of the pollution control plan is 0.19 which determines the significance of environmental aspects from viewpoint of customers. The value in Table 4 means that there is dependence and the degree of relative impact between two factors. For example, C_{11} has a very strong relation with financial efficiency as give 9. Hence, the aggregated relative importance of the factors on the basis of their interdependence was computed by using the sum of multiplication of each criterion to the corresponding requirement weight. Then a normalization formula releases the desired weights we needed.

Table 4 has been produced by making pairwise comparison among candidate suppliers with respect to each decision factor (d_1). The obtained weigh of each matrix displays the each column of Table 5. As seen the row of weights has been adopted from Table 4 final weights.

Phase Three: A third questionnaire was used to evaluate the performance of the ten candidate suppliers with respect to each decision criteria. Experts were asked to compare suppliers with respect to each decision criterion. Nine tables were composed and the relative supplier weights determined. Tables 13 and 14 show two of these pairwise comparison tables, namely, the one obtained for d3 (delivery time) and the one obtained for d8 (CSR), respectively. The remaining tables, with respect to the other criteria, were computed similarly.

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Table 4. QFD matrix and computation of main decision criteria

	Decision criteria									
Customer attitudes	**Financial efficiency (d1)**	**Quality (d2)**	**Flexibility, Delivery (d3)**	**Pollution control plan (d4)**	**EMS (d5)**	**Reverse logistic plan (d6)**	**Energy management system (d7)**	**CSR (d8)**	**Employment train plan (d9)**	**Weight of Requirements**
C_{11}	9						3			0.0688
C_{12}		6		3	3					0.1068
C_{13}		3								0.0974
C_{14}			6							0.0922
C_{21}				6	3	3	3			0.1359
C_{22}	3				3					0.1064
C_{23}	3				3					0.0595
C_{24}				6	3					0.0671
C_{31}								6	3	0.0584
C_{32}	3						6	3		0.0395
C_{33}				3				3		0.0538
C_{34}								3	6	0.1142
Aggregated weights	1.235	0.933	0.553	1.700	1.427	0.408	0.851	0.973	0.860	8.941
Normalized weight of criteria	0.138	0.104	0.062	**0.19**	0.16	0.046	0.095	0.109	0.096	

Table 5. Initial decision matrix for VIKOR process

Weight of QFD	**0,138**	**0,104**	**0,062**	**0,19**	**0,16**	**0,046**	**0,095**	**0,109**	**0,096**
suppliers	d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9
A_1	0.13	0.096	0.115	0.084	0.08	0.115	0.097	0.078	0.077
A_2	0.072	0.091	0.099	0.092	0.089	0.091	0.101	0.111	0.099
A_3	0.131	0.098	0.089	0.156	0.151	0.165	0.115	0.113	0.11
A_4	0.063	0.072	0.066	0.088	0.083	0.068	0.095	0.167	0.054
A_5	0.063	0.094	0.121	0.059	0.085	0.046	0.055	0.051	0.081
A_6	0.071	0.1	0.101	0.065	0.086	0.067	0.088	0.065	0.066
A_7	0.125	0.135	0.099	0.121	0.07	0.137	0.095	0.123	0.1
A_8	0.19	0.138	0.087	0.177	0.165	0.111	0.153	0.158	0.13
A_9	0.093	0.101	0.114	0.049	0.096	0.112	0.106	0.086	0.172
A_{10}	0.062	0.075	0.109	0.109	0.096	0.088	0.095	0.047	0.11

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Table 6. Best and worst ideal values for each criterion

	d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9
f+	0.19	0.14	0.12	0.18	0.16	0.16	0.15	0.17	0.17
f-	0.06	0.07	0.07	0.05	0.07	0.05	0.05	0.05	0.05

Table 7. Weighted utility decision matrix

	d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9	S
A_1	0.0651	0.06584	0.00674	0.13716	0.14436	0.01917	0.0543	0.08099	0.07755	0.65121
A_2	0.12774	0.07476	0.02466	0.12566	0.12915	0.02848	0.05002	0.05103	0.05934	0.67084
A_3	0.06378	0.06266	0.03654	0.03117	0.02211	0	0.03658	0.04965	0.05074	0.35323
A_4	0.13789	0.104	0.062	0.13215	0.13932	0.03758	0.05587	0	0.096	0.76481
A_5	0.13695	0.0686	0	0.17538	0.13538	0.046	0.095	0.10558	0.07441	0.83731
A_6	0.12903	0.06049	0.02313	0.16611	0.13272	0.03789	0.063	0.09267	0.08622	0.79127
A_7	0.0703	0.00493	0.02519	0.08287	0.16	0.01054	0.05567	0.04005	0.05908	0.50862
A_8	0	0	0.03783	0	0	0.02087	0	0.00811	0.03439	0.10119
A_9	0.10449	0.059	0.00791	0.19	0.11725	0.0204	0.04515	0.07382	0	0.61801
A_{10}	0.138	0.09891	0.01332	0.1006	0.11635	0.02963	0.05553	0.109	0.05041	0.71175

Phase Four: At this stage, the performance ratings of the ten suppliers (Phase III) and the weights of the decision criteria (Phase II) were integrated to compose the initial decision matrix. This matrix is shown in Table 5. Because this matrix is already normalized, so we must compute the best f_i^* and the worst f_i^- values of all criterion. It is noticed that all the decision criteria are classified as benefit.

Phase Five: Next step is to calculate the utility and the regret measure using formula 9 and 10 as it is shown in Table 7. As it is seen in Table 8, the alternatives are sorted using VIKOR algorithm and alternative A_8 is considered as the best option while A_5 must be the worst one. VIKOR gives the ability to check the stability of the archived ranking scores. This is the power and advantage of this method to others. We have considered different values of v like "voting by majority" (v>0.5), with "consensus" (v=0.5) and with "veto" (v<0.5). The results were similar and this certifies the robust performance of VIKOR in this decision making problem.

In this way, alternative are arranged as:

$$A_8>A_3>A_7>A_2>A_1>A_{10}>A_4>A_9>A_6>A_5$$

To test the validity and consistency of the rankings obtained, we have computed the Spearman ranking correlation coefficient between COPRAS and VIKOR. This coefficient allows comparing different MCDM methods and measuring their efficiency. COPRAS and VIKOR coincide in the top three ranked suppliers: the first, second and third positions are occupied by A_8, A_3 and A_7, respectively. The two methods agree on the three worst suppliers: A_9, A_6 and A_5. The correlation coefficients are very high (93%) and significant at the 0.01 level. Thus, any of the methods constitutes a reliable ranking procedure that can be used by the managers.

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Table 8. Alternative's ranking using VIKOR

Alternatives	S		R	Q	Ranking
A_1	0.65121		0.14436	0.72362	5
A_2	0.67084		0.12915	0.687	4
A_3	0.35323		0.06378	0.25648	2
A_4	0.76481		0.13932	0.78424	7
A_5	0.83731		0.17538	0.95198	10
A_6	0.79127		0.16611	0.89022	9
A_7	0.50862		0.16	0.67817	3
A_8	0.10119		0.03783	0	1
A_9	0.61801		0.19	0.85104	8
A_{10}	0.71175		0.138	0.74386	6
S*	0.10119	R*	0.03783		
S^-	0.83731	R^-	0.19		

CONCLUSION

This chapter has proposed an integrated multi-criteria decision making (MCDM) approach to sustainable supplier selection problems (SSSPs). In order to solve a SSSP several tasks must be performed: the sustainability factors must be identified; the interdependencies among these factors must be analyzed; the overall performance of the suppliers must be evaluated and the suppliers ranked. The chapter proposed a method articulated in five phases where AHP is integrated with QFD to weight customer factors and decision criteria, while VIKOR ranks the suppliers. With the proposed model, it is aimed to contribute to the literature on SSSPs through forming a systematic approach to analyze specific sustainable development elements and the need for an adequate strategy to deal with the reciprocal influence between stakeholder/customer variables and decision criteria. It is figured out that a systematic analysis of the interdependencies existing among customer variables and technical decision criteria allows not only to detect a clear hierarchical structure for the all the relevant sustainable factors and sub-factors, however to weight the decision criteria based on the importance given to customer needs. The proposed setting supplies a flexible method that delivers coherent and reliable solutions allowing for a broad range of applications to real life situations.

The managerial implications of the proposed model are clear. It brings an assessment tool that can be implemented to demonstrate a network of suppliers satisfying economic features together with environmental and/or social requisites usually valued by customers. The proposed framework has been used to analyze a case study of a diary company. The company used for the investigation is a leading company in the food production and distribution sector. Dairy companies face a considerable amount of market competition while trying to gain a significant market share and competitive advantage. One of the main goals for food companies is to develop green food processes in order to obtain some international standard certificate, which can constitute a very significant competitive advantage in some economic situations. In particular, the ISO standards are often considered to be a priority by many clients. Being part of the production system, suppliers must be assessed and sorted using standardized regulations within a common framework of analysis.

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Even it is stated that the proposed framework can be implemented in the area of supplier evaluation by other companies like textile and automotive etc. it requires a serious effort on the side of the operation managers, who must apply their judgment and knowledge to carefully choose the right group of experts. Simultaneously, it is imperative that the evaluations/data provided by the experts are accurate and as objective as possible. So, the subjectivity characterizing the selection of experts and the interpretation of the data is a limitation of the model. Indeed, the wrong choice of experts by the manager as well as the inaccurate analysis of just one expert may cause the selection of less than efficient suppliers, imposing an opportunity cost on the company in terms of efficiency losses and foregone profits.

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Chapter 3
Benchmarking Sustainability Performance of Suppliers Using ISO 14001 and Rough Set QFD-Based Approach

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ABSTRACT

Supply chain management plays an important role in design, development, manufacturing, etc. and has key impact on company's overall environmental performance. Recently, green supply chain management has gained great interest from researchers and practitioners. Consideration has been given to consider environmental factors in entire supply chain starting from procurement, production, transportation, consumption, and post-disposal of products to make the whole product life cycle green. And those companies implementing ISO 14001 are controlling and minimizing risks not only internally but also externally with their suppliers. In this chapter, the authors are benchmarking sustainability performance of suppliers using ISO 14001 and rough set QFD. For this objective, firstly they identify the requirements for green supply chain planning on the basis of ISO 14001. Then, they evaluate the suppliers on the basis of these requirements using a QFD-based approach. To handle the uncertainties arising due to lack of or limited data, rough set theory is used. The results show that the proposed approach can effectively handle imprecise information and facilitates selection of green supply chain initiatives in a structured way.

INTRODUCTION

Green supply chain management involves a thinking of supply chain management with concern of environment factors from green purchasing to the end of the product cycle including product design,

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manufacturing, distribution, final delivery of products, use, reuse and recycle i.e. reducing packaging and waste, developing green suppliers and developing more eco-friendly products and reducing carbon dioxide emissions in all of the supply chain processes. In recent years, greening the supply chain has become a progressive concern for the success of companies and a challenge for logistic managers because the traditional approaches to supply chain management are not enough to be effective in today's market. And the first most important step towards greening starts from procurement and most important aspect of procurement is supplier selection. In this paper, our focus is on benchmarking sustainability performance of suppliers using ISO 14001 and rough set QFD. How buyer organizations can improve their environmental performance by selecting suppliers based on their conformance to ISO 14001 requirements.

The International Standard organization (Foster, 2010): ISO has developed a series of standards for quality systems for organizations. ISO 9000-2000(Quality Management System for fundamentals and vocabulary), ISO 9001-2000 (Quality Management System- Requirements), ISO 9004-2000 (Quality Management System- Guidelines for performance improvement), ISO 14000- (International standard for Environment Compliance). ISO14000 series contains a set of guidelines for developing systems and practices in environment area. It has six sectors, each having one or more standards: 1) ISO 14001 and ISO 14004: Environmental Management Systems. 2) ISO 14010 to ISO 14012: Environmental Auditing. 3) ISO 14020 to ISO 14025: Environmental Labels and Declarations. 4) ISO 14031: Environmental Performance Evaluation. 5) ISO 14040 to 14043: Life Cycle Assessment (LCA). 6) ISO 14060: Environmental Aspects in Product Standards.

The standard ISO 14001:2004 EMS is a framework that assists companies to manage impact of their activities on the environment in a better way. This framework is based on Plan-Do-Check-Act cycle (PDCA) which means that companies must focus on identifying and continuously improving their environmental performance. Specifically, organizations implementing ISO 14001 standard have to meet certain requirements or key elements that can be classified into five main categories as shown in figure 1 (MacDonald, 2005). A third party certification is needed to evaluate the organization's procedures and site visits to check conformance with respect to implementing ISO 14001.

The ISO 14001 EMS implementation is done in a step by step approach. It involves 15 different steps namely obtain top management commitment, set up an environmental steering committee, understand the company's and ISO 14001 Requirements, train the environmental team and employees, establish an effective environmental management system, establish environmental policies and procedures, create sound environmental management programs, maintain documentation and make it accessible, establish a functional process of recording for the EMS, review of EMS by management, initiate and conduct environmental auditing, select ISO 14001 standard, get registered and maintain your management system. These steps are used for the integration and implementation of ISO 14000 family but in this paper it is used specifically for the implementation of ISO 14001 for better EMS practices in the business (Ball, 2002).

In this paper, rough set based QFD is implemented to determine the best performing supplier with respect to ISO 14001 requirements. The rough set theory approach is used to handle the uncertainties in decision maker's evaluation. QFD is implemented because it is a proven methodology for achieving total customer satisfaction.

To complete the investigation the paper starts with literature review to introduce the background of the techniques used in this concern. Then we proposed a solution for the investigation. We implemented QFD for selecting best supplier for the green supply chain planning, and then Rough set based QFD is implemented to control the enlargement of data with a conclusion in the end.

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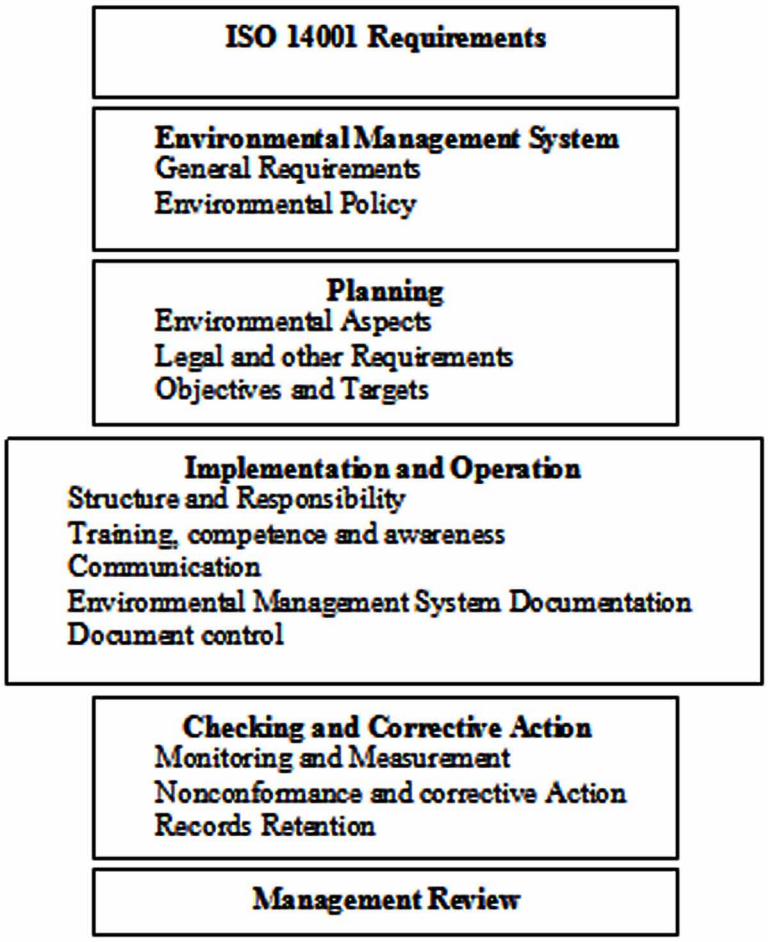
Figure 1. Requirements of ISO 14001



LITERATURE REVIEW

Table 1 presents the various approaches available in literature for sustainability performance of suppliers. It can be seen from the table 1 that ANP is the most commonly used approach.

In recent years, there have been studies on application of QFD for product development (Zhai, Khoo, & Zhong, 2009). Another study (Dai & Blackhurst, 2012) used AHP and QFD in sustainability perspective, four phase study for supplier assessment (Zhang, 1999). It used a life cycle approach for environmentally conscious manufacturing by integrating LCA and LCC into QFD matrices to develop a new green QFD II. All these papers used these famous techniques for developing green supply chain but none used rough set-based QFD for developing green supply chain. Another paper used (Yang, Khan, Sadiq, & Amyotte, 2011) rough set theory based QFD for environmental performance evaluation which gave an idea to generate rough set-based QFD to develop green supply chain.

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Table 1. Sustainability performance of suppliers

Problem	Technique	Author
Green supplier development programs	Fuzzy c-means and VIKOR	Akman (2015)
Evaluating green supplier development programs	Grey based DEMATEL	Fu et al. (2012)
Green supplier development programs	Grey-analytical network process	Dou et al. (2014)
Green supplier selection model	AHP	Lee (2009)
Green supplier evaluation	Multi-objective decision analysis	Lu et al. (2007)
Supplier selection in green supply chain management	DEMATEL	Hsu et al. (2013)
Green supplier selection	Artificial neural network and MADA	Kuo et al. (2010)
Evaluating green supplier's performance	Fuzzy multi criteria approach	Shen et al. (2013)
Evaluate the green supply chain management practices	Fuzzy DEMATEL	Lin (2013)
Green supply chain management practices	Fuzzy ANP	Büyüközkan and Çifçi (2012)
Evaluation of green supply chain management practices	Fuzzy VIKOR	Rostamzadeh et al. (2015)
Green supply chain practices evaluation	Rough sets and Fuzzy TOPSIS	Sarpong et al. (2014)
Evaluate green supply chain practices	TODIM	Tseng, et al. (2014)
Evaluating green supply chain management	Network data envelopment analysis	Mirhedayatian et al. (2014)
Green supply chain performance measurement	Fuzzy ANP-based balanced scorecard	.Bhattacharya et al. (2014)
Sustainability of supply chain management,	Two-stage data envelopment analysis	Khodakarami et al. (2015)
Green supply chain management performance	Fuzzy DEMATEL	Lin et al. (2011)
Evaluate sustainability in supply chain networks	Data envelopment analysis	Tajbakhsh and Hassini (2015)
Firm's green supply chain management	Grey relational analysis	Tseng and Chiu (2013)
Evaluating environmentally conscious manufacturing programs	ANP	Sarkis (1999)
Business strategy selection of green supply chain management	Analytic Network Process	Chen et al. (2012)
Third party reverse logistics service provider selection	fuzzy TOPSIS	Kannan (2009)
Selection of a reverse logistics project	ANP and goal programming	Ravi et al. (2008)
Evaluating third-party reverse logistics providers	ANP	Meade and Sarkis (2002)
Selecting a third-party reverse logistics provider	ANN and fuzzy AHP	Efendigil et al (2008)
Selection of reverse logistics provider	ISM and fuzzy TOPSIS	Kannan et al. (2009)
Selecting third-party reverse logistics providers	Imprecise Data Envelopment Analysis	Saen (2009)

SOLUTION APPROACH

The Quality function deployment (QFD) or "House of Quality" is the most commonly used technique to convert customer requirements into specifications for developing innovative ideas in new product and services. In this paper, a solution approach based on QFD requirements is determined for the best performing supplier with respect to ISO 14001. The proposed approach of QFD for selecting best supplier for the green supply chain planning consists of:

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1. Identification of customer requirements (HOW's or abbreviated as CR) and technical requirements (WHAT's or abbreviated as TR).
2. Identification of correlations between HOW's and WHAT's.
3. Selecting the highest ranked technical requirement.

Conventional mathematical logic was not able to manipulate the subjective data or vague data in QFD analysis. Rough set theory which is used to deal with approximating vague descriptions such as (strong, somewhat or weakly associated) by means of the boundary region of a set. The rating done by the decision makers may not be accurate or might be inconsistent so to deal with imprecise descriptions of customer requirements and technical requirements we have used rough set theory. The customer requirements are in generally qualitative in nature. For example, requirements for implementing ISO 14001 are provided in qualitative form. For effectively implementing ISO 14001, we need to know what would be the best way to do so (HOW's) and how importantly is it associated (strong, somewhat or weakly associated).

QFD

The QFD or House of Quality (Evans & Lindsay, 2005; Foster, 2010; Yang et al., 2011) is used to convert the customer's need into technical specifications. The customer requirements (also known as voice of customer) is the primary input to the QFD process and the translation of customer requirements "what customer wants" into technical requirements "how the company will give" helps the top management to stimulate new ideas. The techniques used in this paper to collect customer demands are voice of customer and checklist for assessing their green initiatives. Second matrix or table contains the technical requirements which are actually the customer requirements but expressed in terms of engineer's language. Technical requirements are referred as HOW's namely T1, T2, T3, T4, T5, T6, T7, and T8 and they must be measurable. These technical requirements are referred to suppliers of the companies. On the top of the roof of QFD is the correlation matrix which shows the degree of interdependence among the technical requirements. The next table will be the relationship matrix which shows whether how much the technical requirement adequately address the customer requirements. This assessment is based on expert experience, customer responses or controlled experiments. Next matrix or table will be for the importance ranking of technical requirements that are of critical importance to satisfy the customer requirements. It consists of absolute importance, relative importance and rank order of technical requirements. To determine which technical requirements to set up. The absolute weight are evaluated for the technical requirements to reach at the end decision for deciding improvement. This is done by calculating relative ranking or a percentage weight factor.

Rough Set Notions

A series of QFD are used to translate the qualitative requirements into quantitative specifications. So firstly, we will be calculating weights of WHATs i.e. the importance for each of customer's needs using rough numbers. Let DM1, DM2, DM3 be the three decision makers and C1, C2 and C3 (Refer to Table 2 and Table 3 for details of customer requirements) be the customer requirements. The customer and technical requirements are numbered 1, 2, 3 .and so on to use short forms for these tables. In Table 5,

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three decision makers assign their importance rating for each of the customer requirement identified with 1-10 assessment scale. (With 10 as most important and 1 as least important).

Rough set theory (Yang et al., 2011) is a mathematical approach to generate reasonable solutions from vague or imprecise information. In this mathematical approach, a boundary region is used to express imprecise information with (U, R) as approximation space, where U is the universe of finite set of objects and R is an Equivalence relation on U.

Let X be a subset of U, i.e. $X \subseteq U$. By the relation $R \subseteq U \times U$, we mean the relation R is an indiscernibility relation which means that we lack a knowledge about the universe U and by $R(C_i)$, we denote the equivalence class of R is known by element C_i. The equivalence relation R represents an elementary portion of knowledge so we are not able to observe individual objects from U only some knowledge is described by this relation.

1. The lower approximation consists of a set of all objects that are certainly (probability = 1) identified as members of set X with respect to R.
2. The upper approximation consists of a set of all objects that are possible (probability = nonzero) identified as members of set X with respect to R.
3. The boundary region consists of members that can neither be ruled in nor be ruled out as members of set X with respect to R.

Now, if a boundary region of a set is non-empty then it implies that the knowledge about the set is inexact or rough. So, X in this case is known as Rough set with respect to R.

And if the boundary region of a set is empty then a set X is known as crisp or exact with respect to R. Thus C_i can be represented by a rough number (RN) with Lower limit

$$\text{Lim (Ci)} = 1/\text{ML} \sum R(Y) \mid Y \in \text{Apr Ci}$$

and

$$\text{Upper limit, } \bar{\text{Lim}}\ (C_i) = 1/M_U \sum R(Y) \mid Y \in \overline{\text{Apr}}\ C_i,$$

where Y is arbitrary object of U, ML is the number of objects contained in the lower approximations of Ci, MU is the number of objects contained in the upper approximations of CiApr $Ci = \cup \{Y \in U/R(Y) \leq Ci\}$ and $\overline{\text{Apr}}\ Ci = \cup \{Y \in U/R(Y) \geq Ci\}$. The interval between the lower limit Lim (Ci) and the upper limit $\bar{\text{Lim}}$ (Ci) is the rough boundary interval of Ci which is denoted as:

$$\text{RBnd (Ci)} = \bar{\text{Lim}}\ (Ci) - \text{Lim (Ci)},$$

Therefore, the rough number will be denoted as follows:

$$\text{RN } (C_i) = \lceil \underline{\text{Lim}}\ (C_i), \bar{\text{Lim}}\ (C_i) \rfloor$$

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Voice of the Customer (VOC)

VOC (Emmett & Sood, 2010) specifies the detailed set of customer wants and needs. They are generally collected at the start of the process to better understand the customer demands. In this paper, the customer will be the company who is seeking to take steps for becoming "green" or its stakeholders who want to reduce the waste and hazardous emissions throughout the supply chain. The customer preferences for use in QFD for VOC are hypothetical in nature. Our focus will be to select best supplier who is following ISO14001 to improve various performances of the company. The voice of customer is as follows: 1) Proper planning for purchasing, specifications, and purchase orders. 2) Identify opportunities to purchase green products and services. 3) Need for creating a list of green products and specifications. 4) Need for gaining knowledge of green products and services. 5) Preferring to buy raw materials from ISO certified suppliers or with eco- labeled raw material. 6) Initiatives to reduce supplier waste and surpluses. 7) Need of support and commitment from management. 8) Participation of employees in green programs. 9) Selecting Green purchasing team. 10) Need to communicate the environmental requirements for raw material with suppliers. 11) Need of communication for greening strategies and decisions among employees and stakeholders. 12) Considering environmental issues before designing to reduce environmental impact. 13) Awareness about the end- results of purchasing before actual procurement of raw material. 14) Minimal usage of raw material. 15) Easy availability of green products and services. 16) Easier compliance with government regulations. 17) Providing environmental friendly packages. 18) Reduce package material. 19) Identify various alternatives of packaging. 20) Identify various methods of transportation of raw materials and disposable materials. 21) Right disposal methods for hazardous material. 22) Efforts to create new, innovative products and services with reduced environmental impacts. 23) Improved image, brand and goodwill.

Customer and Technical Requirements

Customer requirements will fall under the following requirements of the checklist of ISO 14001 that will help to select the best supplier who will help to make supply chain green. Three different suppliers have been selected and three different decision makers will mark their rating, which will act as the technical requirements and the customer requirements are collected according to the checklist of ISO 14001 and are presented in Table 2.

Identifying Customer Requirements for Companies

Identifying customer requirements is the first step in the process of QFD which was explained above and now we are applying it on the selected suppliers of the company's. These customer requirements are collected according to the format of the checklist provided in Table 2. Here 1-a), 1-b), 2-a)….so on is referred to each question in the checklist. And to construct Table 4, data is extracted from all the companies report's according to the green initiatives taken by the suppliers and according to what the checklist requires.

More detailed customer requirements can be used to construct QFD, but we will be using only C1, C2and C3as customer requirements to show how the methodology can be used to construct QFD for supplier selection.

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*Table 2. ISO 14001 Checklist (*addr.: Addressed (Yes/No/NA)*

Company Name:		
Period:	**Title of Report:**	
ISO 14001 Checklist		addr.?*
1. General requirements: a) Is the scope clearly defined, documented, maintained with all the environmental aspects included or excluded? b) Are the requirements contained in ISO 14001 established and maintained by the company?		
2. Environmental Policy: a) Is the company having Environment policy? b) Is it sanctioned by top management? c) Is it publicly available? d) Is it communicated to all employees? e) Is the environmental policy: I. Relevant to the scope? II. Appropriate to the nature and scale of the company f) Is it committed to: I. Continual improvement? II. Prevention of pollution? III. Laws and regulations		
3. Environmental aspects, impacts and legal obligations: a) Has a procedure been established, implemented and maintained to identify the environmental aspects of its current and relevant past activities? b) Has the company established procedures?: I. To identify laws, regulations and other requirements relevant to the organizations environmental aspects, document them and keep it up to date? II. To identify the potential for and respond to accidents and emergencies? III. To prevent and mitigate impacts of accidents and emergencies.		
4. Objectives, Targets and Programs: a) Are they established at each relevant function and level in the organization? b) Are they documented? c) Did the company taken into account the significant environmental aspects, legal, business requirements, and adequate technology d) Did the company established, implemented programs with responsibilities at each level, time frames and the means to achieve its objectives and targets.		
5. A Documented System: a) Document has: I. Has environmental policy, objectives, targets, scope? II. The description and interaction of main elements with their references. III. Document, records for effective planning, operation and control of activities linked with environmental aspects b) Has the procedures documented and implemented for controlling ISO 14001 documents to ensure that they are up to date, accurate, and easily accessible with different versions and maintenance of archives of old version and external documents?		
6. Roles, Accountability and Responsibility: a) Have the responsibilities and authorities for EMS been defined, documented and communicated? b) Are the required resources provided for implementation, maintain, control and improvement of EMS? c) Identified personnel to report the EMS function and performance to top management?		
7. Awareness, training and Communication: a) Communicate the environmental policy with all employees? b) Informed about roles and responsibilities? c) Identify general EMS awareness/training needs for all employees and managers and ensure that employees involved in work that contributes to significant environmental aspects are trained? d) Communicate relevant requirements to suppliers, contractors and other external stakeholders regarding significant environmental aspects?		
8. Monitoring, Measurement and Reporting: a) Are documented procedures established, implemented and maintained to periodically evaluate compliance with environmental legislation and other requirements? b) Has the procedure been documented and implemented to monitor, measure and report: I. Significant environmental aspects and impacts, operational controls and performance toward objectives and targets? II. EMS non conformances and corrective and preventative actions? III. EMS non conformances and corrective and preventative actions? IV. The planning and undertaking of internal audits, assessments or inspections, as well as selection of auditors and training?		
9. Management Review: a) Does periodic review take place for ensuring of proper structure, performance and effectiveness? b) Do the management review: I. Identify and document opportunities for improvements and changes to the EMS? II. Consider the effectiveness of actions and recommendations resulting from prior management review.		
10. Assessment Outcome		

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Table 3. Checklist of ISO 14001 for companies

Refer to points from checklist	*ID*
1-a)	$\mathbf{C_1}$
1-b)	$\mathbf{C_2}$
2-a)	$\mathbf{C_3}$
2-b)	$\mathbf{C_4}$
2-c)	$\mathbf{C_5}$
2-d)	$\mathbf{C_6}$
2-e)-I	$\mathbf{C_7}$
2-e)- II	$\mathbf{C_8}$
2-f)- I	$\mathbf{C_9}$
2-f)- II	$\mathbf{C_{10}}$
2-f)- III	$\mathbf{C_{11}}$
3-a)	$\mathbf{C_{12}}$
3-b)- I	$\mathbf{C_{13}}$
3-b)- II	$\mathbf{C_{14}}$
3-b)- III	$\mathbf{C_{15}}$
4-a)	$\mathbf{C_{16}}$
4-b)	$\mathbf{C_{17}}$
4-c)	$\mathbf{C_{18}}$
4-d)	$\mathbf{C_{19}}$
5-a)- I	$\mathbf{C_{20}}$
5-a)- II	$\mathbf{C_{21}}$
5-a)- III	$\mathbf{C_{22}}$
5-b)	$\mathbf{C_{23}}$
6-a)	$\mathbf{C_{24}}$
6-b)	$\mathbf{C_{25}}$
6-c)	$\mathbf{C_{26}}$
7-a)	$\mathbf{C_{27}}$
7-b	$\mathbf{C_{28}}$
7-c)	$\mathbf{C_{29}}$
7-d)	$\mathbf{C_{30}}$
8-a)	$\mathbf{C_{31}}$
8-b)- I	$\mathbf{C_{32}}$
8-b)- II	$\mathbf{C_{33}}$
8-b)- III	$\mathbf{C_{34}}$
9-a)	$\mathbf{C_{35}}$
9-b)- I	$\mathbf{C_{36}}$
9-b)- II	$\mathbf{C_{37}}$
10)	$\mathbf{C_{38}}$

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Table 4. Technical requirement

Technical requirements	Suppliers
T_1	Supplier 1
T_2	Supplier 2
T_3	Supplier 3

Identifying Technical Requirements for Suppliers

Technical requirements are the three suppliers. Information on their fulfillment of customer requirements (ISO 14000 checklist) can be obtained from the sustainability, environmental or annual reports of all the companies. We will be using three technical requirements (suppliers) to show the implementation of the methodology. So, T1, T2 and T3 will be used in numerical application.

NUMERICAL APPLICATION

Rough Based QFD

A series of QFD are used to translate the qualitative requirements into quantitative specifications. So firstly, we will be calculating weights of WHATs i.e. the importance for each of customer's needs using rough numbers. Let DM1, DM2, DM3 be the three decision makers and C1, C2 and C3(Refer to Table 2 and Table 3 for details of customer requirements) be the customer requirements. The customer and technical requirements are numbered 1, 2, 3 .and so on to use short forms for these tables. In Table 5, three decision makers assign their importance rating for each of the customer requirement identified with 1-10 assessment scale. (With 10 as most important and 1 as least important).

Importance Rating for Customer Requirements

Using rough numbers in Table 6, we calculate the final importance rating. Taking C1 as an example, we have two classes namely '7' and '9' and using rough set theory formulas stated above we can calculate lower and upper limits of class 7.

$$\text{Lim (Ci)} = \text{R (C2)} = 7$$

Table 5. Rating for decision maker's importance

Customer Requirements(CR's)	Importance Rating		
	DM_1	DM_2	DM_3
C_1	9	7	9
C_2	7	9	9
C_3	7	9	7

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Table 6. Quantification of customer survey data into rough numbers

Customer Requirements (CR)	Importance Rating				
	DM_1	DM_2	DM_3	(FIR)	Round off FIR
C_1	⌈8.33,9 ⌋	⌈7,8.33 ⌋	⌈8.33,9 ⌋	⌈7.88,8.77⌋	⌈8, 9⌋
C_2	⌈7,8.33⌋	⌈ 8.33,9⌋	⌈ 8.33,9⌋	⌈7.88,8.77⌋	⌈8, 9⌋
C_3	⌈7,7.66 ⌋	⌈7.66,9⌋	⌈7,7.66 ⌋	⌈7.22,8.1⌋	⌈7, 8⌋

$\bar{Lim}$ (Ci) = (R (C1) + R (C2) + R (C3))/3 = 8.33

Rough number = ⌈ Lim (Ci), $\bar{Lim}$ (Ci) ⌋ = ⌈7, 8.33 ⌋

In Table 6, Final importance rating is obtained by aggregating the individual evaluations into group as

$$FIRi = 1/n \sum_{j=1}^{n} IRj$$

where FIRi denotes the weight of each WHAT, n is the total number of decision makers and IR is the importance rating of each WHAT firmed by the jth decision maker, FIR is the final importance rating which is quantified into rough numbers.

FIR1= (⌈8.33, 9 ⌋ + ⌈7, 8.33 ⌋ + ⌈8.33, 9 ⌋)/3 = ⌈7.88, 8.77⌋.

and final FIR is obtained by rounding it to make one digit number. Using rough number theory set explained above we quantify Table 5 into rough number as following in Table 6:

Quantification of Customer Survey Data Using Rough Numbers

Relationship Between the Customer and the Technical Requirements

To draw the relationship matrix, we need to specify each "HOW's" which are the customer requirements for satisfying "WHAT's" which are the technical requirements as relationship matrix describes the degree of impact of each HOW's on the achievement of each WHAT's.

Let us assume as T1, T2 and T3as the HOW's representing various technical requirements (refer to Table 4 for technical requirements) that are needed to fulfill the customer requirements. Three decision makers evaluate the relationship between each of the customer requirements "HOW's" and the technical requirements "WHAT's which is shown in Table 7 and then rough number is calculated in same way as shown by an example above and the rough numbers are represented in Table 8. It uses values varies from 1 - weak association, 3 - somewhat associated, 9 - strongly associated and a missing value indicate that the decision maker is unable to select a suitable value. As we are using a rough set theory with QFD to handle vague descriptions, uncertain values and inconsistency in QFD analysis. So, we will be using 1 at a time 9 another time for missing values to calculate the lower approximations and upper approximations in case of any missing value.

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Table 7. Decision maker's evaluations

Customer Requirements(CR's)	Relationship Matrix			
	Decision maker's	T_1	T_2	T_3
C_1	DM_1	3	3	3
	DM_2	3	3	1
	DM_3	9	9	1
C_2	DM_1	9	9	1
	DM_2	9	9	3
	DM_3	3	3	1
C_3	DM_1	3	3	1
	DM_2	3	3	1
	DM_3	3	1	1

Rating by Decision Makers on the Relationship Between Hows and Whats

As we can see that, there is no missing information but if there is missing information then we will put 1 at a time and other time we put 9 and then we calculate the rough number. Using rough number theory set explained above we quantify the relationship matrix Table 7 into rough number in Table 8. Table 8 is round off to a zero level and can be represented as "R'_{ij}" for the adjusted relationship between the i^{th} WHAT and the j^{th}HOW.

WHAT AND HOW RELATIONSHIP REPRESENTED BY ROUGH NUMBER

Correlation Matrix

The correlation matrix defines the relationship between HOW's. Table 9 provides the correlation between HOWs. We can also use symbols instead of numbers and then put the values and convert them into rough numbers, but we are using numbers for assigning the correlation between HOW's. But here as with traditional QFD, we have a scale with 3 positive relations, 9- strong positive relation, -3 negative relations and -9 strong negative relations for showing the correlation.

Table 8. WHAT and HOW relationship represented by rough number

CR's (Customer's Requirements)	Relationship Matrix		
	T_1	T_2	T_3
C_1	⌈4,6⌋	⌈4,6⌋	⌈1,2⌋
C_2	⌈6,8⌋	⌈6,8⌋	⌈1,2⌋
C_3	⌈3,3⌋	⌈2,3⌋	⌈1,1⌋

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Table 9. Assessments on the correlations between HOW's

Technical Requirements (TR's)	Correlation Matrix		
	T_1	T_2	T_3
T_1	9 9 9	9 9 3	9 3 3
T_2	9 9 3	9 9 9	3 3 3
T_3	9 3 3	3 3 3	9 9 9

Assessments on the Correlations Between HOWs

If there is any unfilled values, then it will not be treated as missing values because these are the relation that either we have some relation or we doesn't have it. So, it will not be treated by the upper formula of missing information. And there is no negative value associated with it. Otherwise, it would have marked as negative too. It may vary from organization to organization that they want to consider only the strong relations or all relations while deciding the output.

Table 10 is the rough number representation of Table 9. In this, we calculate the rough number as explained above in methodology. We have calculated the rough number according to the majority of decision makers. For example, if the decision makers mark (3, 3, 9), we calculated the rough number as (3, 3), because majority is 3.

CORRELATIONS BETWEEN HOWS REPRESENTED BY ROUGH NUMBERS

Importance of HOWs

The HOW's (technical requirements) are prioritized according to their importance of rating in Table 11 and the importance ratings are calculated according to the following steps as discussed below:

Table 10. Correlations between HOW's with rough numbers

(TR's)	Correlation Matrix		
	T_1	T_2	T_3
T_1	⌈9,9 ⌋	⌈9,9⌋	⌈3,3 ⌋
T_2	⌈9,9⌋	⌈9,9⌋	⌈3,3⌋
T_3	⌈3,3⌋	⌈3,3⌋	⌈9,9⌋

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Table 11. Importance of How's

	T_1	T_2	T_3
Absolute Importance	⌈101, 150⌋	⌈94, 150⌋	⌈23, 44⌋
Absolute Factor	⌈0.46, 0.44⌋	⌈0.43, 0.44⌋	⌈0.10, 0.12⌋

Step 1: Aggregation: Absolute importance is calculated by first multiplying the numerical value in each of the cells of the relationship matrix by the associated CR's importance rating. Then, we sum up column wise to give the importance absolute rating.

$$I_j^{bn} = \sum_{i=1}^{m} (FIRi * R'ij$$

where I_j^{bn} is the absolute importance of the jth HOW, FIR is the weight of the ith WHAT, R´ij is the adjusted relationship between the ith WHAT and the jth HOW and m is the number of WHAT's. (i=1, 2, 3….m; j= 1, 2, 3…n)

Step 2: The absolute factor: The absolute factor is calculated by the method:
(Absolute rating lower limit of each HOW's)
(Aggregate of all absolute rating's lower limit)
(Absolute rating upper limit of each HOW's)
(Aggregate of all absolute rating's upper limit)

Importance of How's in Terms of Rough Numbers

The highest ranking is of T1which means supplier 1 is the best alternative for green procurement. The relative weight and relative factors are not calculated because we have not taken account the sales and target values (benchmarking). By looking on correlation matrix in Table 10, we can see that it has very strong relationship between T2?

CONCLUSION

In this paper, we present a hybrid approach integrating Rough set theory with QFD for benchmarking the sustainability performance of the suppliers using ISO 14001 and rough based QFD. We use the Australian government ICT sustainability plan 2010- 2015 mandatory guidelines as a standard format for customer requirements. Selecting three random suppliers of the company and rating them according to their performances. Then, Using rough numbers the three decision maker's imprecise information was converted to rough boundary intervals bounded by upper and lower limits, which can be directly computed from raw data without any need for subjective adjustments or assumptions. The rough set theory also controlled the enlargement of rough boundary intervals in QFD analysis. A hypothetical rating was

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done to show as an example to explain the implementation procedure. Through the proposed work, we are able to make more reliable decisions for selecting the best supplier according to their performances for green planning and thus improve the quality of decision making in green supply chain. Then, the widely used rough set theory has also some limitations or drawbacks like the information inserted into QFD is highly based on experts subjective knowledge and experience, which may not be a good agreement with actual facts. Secondly the boundary intervals may expand rapidly and ultimately influence the decision making in QFD.

The results of our study show that the supplier 1 comes out to be the best with very little difference or high correlation of supplier 2. But this priority can be changed with different suppliers with their performances and experts input related to them. The main limitation of this research is that the result may change from experts input and knowledge.

FUTURE WORK

There are several opportunities to extend the research presented in this paper. Data collection can be made real. Also, analysis can be done on each area of green supply chain. For example, measuring the impact on green purchasing instead of whole green supply chain. This technique can also be implemented by companies in which the end users want to reduce waste or hazardous emissions in the supply chain. For example, customers, employees, owners, management, shareholders, suppliers, distributors, manufacturers, retailers, recyclers, waste management organizations, financial organizations, partners, competitors, government, NGOs, local community, social activists, interest groups, media, scientific community, safety advocates, environmental groups etc. The customer requirements will be the demands and needs of these customers to reduce waste or hazardous emissions in the supply chain through specifications known as technical requirements. Companies can focus on each sub element or whole of supply chain to identify if a more environmentally sound approach can help to cure the inefficiencies like where raw materials are wasted, resources are underutilized and unnecessary energy is used due to inefficient equipment's and can come out with best approach similar to the proposed QFD methodology. There is no rule on the number of decision makers. The only limitation is decision making software requirements such as ANP which can handle only limited number of pair wise comparison matrices obtained from decision makers. In this paper we only considered environmental factor but other factors like economic, external pressure, availability of material, demand, quality etc can also be selected to determine which factors play more important role while procurement.

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Chapter 4
A Circular Economy Perspective for Dairy Supply Chains

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ABSTRACT

The environmental issues and the projected world population increase have brought into light many different terms and concepts. For over 20 years, sustainability attracts the main focus of most researchers; however, recently the concept of circular economy (CE) is considered to be its successor. CE is based on a closed loop supply chain, where waste is minimized and reintroduced into the supply chain, thus requiring a systemic change. In the agri-food sector, the CE principles have many possible applications. This chapter provides a CE perspective for the dairy supply chain by identifying and analyzing the associated technologies and strategies through a literature review taxonomy based on the related stage of the supply chain.

INTRODUCTION

Over the past few years, the emerging environmental issues have been in the center of attention of people, cities, countries and organisms all around the world. In 1992, when the United Nations Framework convention on Climate Change was adopted, the problems of climate change came to light, leading to the Kyoto Protocol in 1997 and the Paris Agreement in 2015 (United Nations, 2017a). Thus, the idea of sustainability was born. It is based on three pillars: the environmental, the social and the economical. In order to be sustainable, a product, company or country needs to balance these three aspects.

At the same time, Circular Economy (CE) has recently gained in importance, with the academic world, policymakers and companies realizing its worth (Geissdoerfer, Savaget, Bocken, & Hultink, 2017) and the EU promoting it (Korhonen, Honkasalo, & Seppälä, 2018). This concept gives life back to the product after its use, aiming to reduce, reuse, recycle and recover materials, as the 4R Frame-

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work suggests (Kirchherr, Reike, & Hekkert, 2017). It is an alternative model to the traditional Linear Economy following the 'take-make-dispose' pattern resulting to environmental and economic impacts (Ellen MacArthur Foundation, 2012).

CE is considered to be a means to achieve sustainability (Ellen MacArthur Foundation & McKinsey Center for Business and Environment, 2015), but there are major differences as well, e.g. their purpose, priorities and beneficiaries (Geissdoerfer et al., 2017). Their main connection is their way of thinking; CE combines sustainability and closed-loop supply chains into the business model of the industry (Preston, 2012), with sustainable development being its main goal (Kirchherr et al., 2017). Thus, while the two have common ground, CE focuses more on the environmental and economic aspects.

Along with the environmental issues, by 2050 the World's population will have reached 9.5 billion people according to UN's projections of 2017 (United Nations, 2017b). This will result in an increase of agricultural production, which is affected by the existing climate change but can also have a negative impact on the environment. The sector is developing globally, with 28.06% production growth in 2016 compared to the 2004-2006 period (FAO, 2018), while it employs 30.7% of the total workforce (World Bank, 2019). Agri-food supply chains, technological solutions for energy production and waste management are only some of the main challenges today. As a result, the term Circular Agriculture, i.e. Circular Economy in Agriculture, has been introduced.

One of the basic types of agriculture is livestock farming. Animal products, by-products and co-products are important for human nutrition and the economy, with the annual consumption achieving an annual growth of 1.2, 0.4 and 1.5% for meat, milk and eggs respectively (FAO, 2013). Dairy products in particular have a critical role, as they are important for human nutrition and development throughout life and represent around 14% of total calorie consumption (FAO, 2013). However, they have an undeniable impact to the environment. According to FAO, more than 10% of Dairy products are lost or wasted in Europe, a lower percentage than most regions but significant nonetheless (FAO, 2011). Most of that percentage is during the consumption period (40-60% of the total), however the percentage during agriculture is also high. Other than waste, there are other important issues; the animals themselves and their feed, the production and distribution of products, but most importantly what happens with leftover products and wastewaters. Considering the above-mentioned population increase, all these challenges present an opportunity for the development of CE.

However, despite the importance of the dairy industry and the considerable amounts of produced waste, there is a lack in the research literature of a holistic framework that analyses the CE perspective of the dairy supply chain, while identifying state-of-the-art technologies that can contribute to this objective. This has been the key motivation for this chapter. To that end, in this chapter, the circular dairy processing system is presented as well as its additional components with respect to the conventional system. Different technologies and solutions are analyzed and discussed along with the resulting classification of relevant literature. This allows for the identification of existing gaps, overlaps and future research areas of CE in dairy supply chain.

The objectives of this chapter are to determine:

- Which are the state-of-the-art technologies aligning with the CE principles?
- How can CE be applied in Dairy Supply Chains?
- What is the future of the CE in Dairy Supply Chains?

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BACKGROUND

As mentioned in the Introduction, CE has been gaining ground the past few years as a concept that can reshape the Economy and the environment. The term has been analyzed in multiple occasions, with more than 114 definitions by 2017 (Kirchherr et al., 2017), while the European Union promotes it on its "Roadmap to a Resource Efficient Europe" in order to achieve resource efficiency (Commission Staff, 2014). The material flows are the main concern CE policies address. In the case of biological nutrients, after they are discarded they can be reintroduced into the natural cycle, while the rest are designed to be circulated by being reused and recycled (Haas, Krausmann, Wiedenhofer, & Heinz, 2015).

Through this process, there is value creation in the material's supply chain. There are four principles that govern this value creation (Ellen MacArthur Foundation, 2013):

- Inner circles: when the material is circled in tighter circles, less resources are being used for its repurposing.
- Longevity of the circle: a product with a longer life, either in the same or in different product circles, keeps creating value for as long as it is being repurposed.
- Product remarketing: the material can be repurposed as a part of a completely different product.
- Better Inputs: cleaner, purer and higher quality materials, chosen in the concept of CE, result in products that can be recycle and reprocessed.

Winans, Kendall, & Deng (2016) categorized the bibliography of the current applications of the CE concept into three categories:

1. **Policies:** The authors review the applications of CE according to the definition and components of policy as defined by Jiao & Boons (2014, 2017). This category includes eco-industrial parks and networks industrial symbiosis networks in Denmark, Sweden, the Netherlands, Italy, United Kingdom, United States of America, China, Thailand and South Africa, most of them promoted by government laws and initiatives. Ghisellini, Cialani, & Ulgiati (2016), however, further taxonomize the bibliography in accordance to the level where the policies are implemented:
    a. **Micro Level:** The smaller companies or the consumer constitute this category, where "Green Consumption", recycling and "Cleaner Production" are the main players.
    b. **Meso Level:** Hubs, parks, clusters and districts with an ecological with ecological consciousness.
    c. **Macro Level:** Wider regions e.g. cities, provinces, networks, countries, or waste management systems and programs.
2. **Value Chains, Material Flows and Product Applications:** In this category, the systems are reviewed according to the product's resource i.e. wood products and by-products, plastics, metals chemicals, agricultural products and waste, water and land.
3. **Innovations in Technological, Organizational and Social Context:** This category includes all the current trends and new technologies that are in harmony with the CE principles.

Consequently, the CE concept can be adopted by businesses, systems or regions of different sizes and of a multitude of products and value chains. The optimal technologies and organizational models that are applicable on each case differ. In 2014, Naustdalslid stated that the decoupling of resources, i.e. energy and materials, and the environment, was an idealistic strategy to implement CE in China, whereas

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"relative decoupling", which is a less aggressive and slower solution. In 2015 Wijkman & Skånberg further studied the delinking by simulating decoupled systems in order to determine the effects of reducing energy use, of increasing the use of Renewable Energy Sources (RES) and of the more efficient use of materials separately. In a system as such, the economic progress does alter the use of resources but optimizes their use and therefore does not affect the ecosystem. After simulations on the effects of CE in Finland, France, the Netherlands, Spain and Sweden, the authors concluded that the countries could reduce their carbon emissions, while achieving improvements in trade and employment (Wijkman & Skånberg, 2015a, 2015b).

This chapter focuses on smaller scale businesses of micro or meso level as they were defined above, producing agricultural goods and in particular dairy products, by-products and co-products. To this end, there have been several studies focusing on evaluating the economic feasibility of producing bioenergy from different agricultural products and manure using Anaerobic Digestors (AD) (Blades et al., 2017; Vega-Quezada, Blanco, & Romero, 2017) or wastewaters (Ferreira et al., 2018). In 2014, Ghisellini et al. compared an Italian and a Polish Dairy Farming Systems. The Italian farm had installed Solar Photovoltaic (PV) and a manure AD to produce energy, while the Polish used manure as a fertilizer. The transition to an energetically self-sufficient system was, according to the authors, efficient, however energy is not the only concern and a balance needs to be sustained for optimal results.

In terms of the design of dairy supply chains in line with the CE concept, Stanchev, Vasilaki, & Katsou (2017) demonstrated a dairy processing farm in the South-West of United Kingdom that produces 42 million liters of milk and 80,000 m^3 of wastewater per year. The linear economy system consists of the Farm stage (1), where the livestock grazes freely or from produced crops (1a), is milked (1b) and then the raw product is sent to the processing industry (1c), and the Manufacturing stage (2), where the product is being processed (2a), packaged (2b) and then distributed (2c) in order to reach the consumer. The systems inputs are materials (ex. packaging), fuels, electricity, chemicals and water, while the outputs are emissions to air, soil and water, and the resulting dairy product, co-product and by-product.

In case of the equivalent circular system, Stanchev et al. (2017) added two more stages aiming to minimize the system inputs and emissions and maximize its production; the Wastewater Treatment stage (3), during which the wastewater is repurposed for production of energy, water and nutrient recycling through Anaerobic Digestion, and Recycling (4).

However, there are many different technologies that can make use of bio-waste in order to produce energy, fertilizers or other products, in order to close the loops and create a supply chain based on the CE principles.

THE CIRCULAR ECONOMY CONCEPT IN THE DAIRY SUPPLY CHAIN

In order to categorize the technologies and strategies associated with CE, the dairy supply chain shall be thoroughly investigated. According to Lowe & Gereffi (2009), the dairy value chain can be separated into four main stages, as shown in Figure 1:

- **Inputs**: According to the authors, this stage consists of forage and animal feed, veterinary services and genetics (breeds). However, the supply chain has even more inputs, the main ones being: (a) materials e.g. packaging, (b) energy e.g. fossil fuels for transportation or electricity for the factory,

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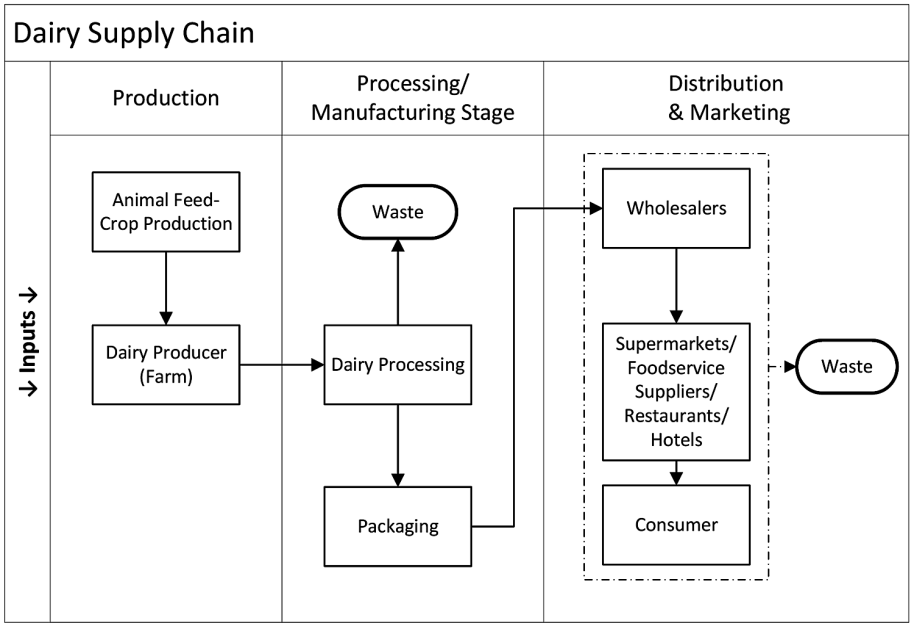
(c) water for the livestock, crops and factory and (d) chemicals e.g. fertilizers. These resources cost money and impose an environmental burden by polluting and reducing natural resources.

- **Production**: This stage consists of the production of milk as a raw material and takes place in the farm. Through water and food consumption, in the stables and with veterinary support, the animals reproduce and produce milk and meat. Lowe & Gereffi (2009) mention there are alternative types of producing systems such as Dairy Cooperatives. These are especially important for smaller scale farms, where the construction of dairy factories is expensive and cannot be carried out by a single farmer and where the competitiveness creates the need and the opportunity for teamwork from smaller farmers. In this stage, animal manure and agricultural residues can be gathered from the farm to be processed as biomass or to produce fertilizers, saving resources and money and protecting the aquifer from chemical contamination.
- **Processing/ Manufacturing Stage**: This is the main field of application of the CE concept. During the Dairy Processing, which includes all the chemical and industrial processes, the dairy products, co-products and by-products are produced with the use of the previous stage's raw material resulting in waste, i.e. wastewaters and unusable whey. This waste however can be used for electricity, heat, transportation fuel, and fertilizers production with the use of the appropriate technologies. The products are later on packaged in order to be transported to the next stage.
- **Distribution & Marketing**: This is the most important stage of all in the value chain in general, as the product is being sold to the consumer through Supermarkets, Foodservice Suppliers and Restaurants, or even directly through vending machines. From the above and according to Lowe & Gereffi (2009), supermarket is the most important middleman accounting for almost half of the total sales. On this stage, waste is created both by the consumer, who throws away the packaging or does not use all the product, but also the intermediaries who throw away a lot of the packaging and also have unsold product that can be reused and recycled in accordance to the CE principles.

Figure 1. The dairy supply chain adapted from Lowe & Gereffi (2009)



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The main outputs of the dairy supply chain are (a) waste and (b) emissions to air, soil and water mainly during the dairy processing. There are two types of waste: one is the organic waste i.e. milk residues, dairy products that go to waste, damaged goods, out-of-date products and wastewaters and the inorganic waste which is the packaging. In order to better understand the first, the dairy production process is presented in Figure 2 based on the relevant bibliography (Durham & Hourigan, 2007; Fenyvessy, Csanádi, & Eszes, 2007; Peacock, 1996). There are three main production phases:

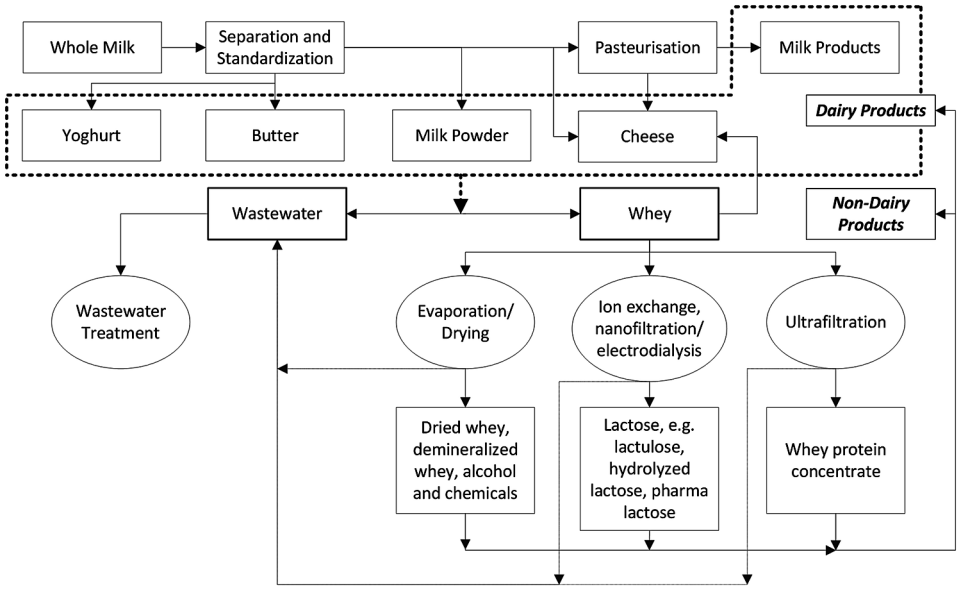
Phase One: The raw milk, after being transported from the farm, is received and stored in the facility.
Phase Two: The milk is separated and standardized producing yogurt, butter, milk powder and certain types of cheese.
Phase Three: Pasteurization occurs, producing cheese and milk products.

Depending on the type of raw milk (it can be from cattle, sheep, goat or even other mammals), there are deferent types of products produce, thus the above phases match accordingly. For example, in the case of cattle milk, whole and skimmed milk products, cheese, milk powder, butter, yogurt, ice-cream, yoghurt desserts are derived.

All these products lead to two types of residues: wastewater and whey. Wastewater, depending on its consistency, is treated in several ways that will be analyzed in the "Wastewater Treatments" subsection of this section. Whey however, can be evaporated, electrodialyzed or ultrafiltrated and produce by-products that can be used back in the processing facilities to produce other dairy products, can be used as a product on its own, sold as a supplement or can even be used for other, non-dairy products (Durham & Hourigan, 2007; Fenyvessy, Csanádi, & Eszes, 2007).

In the concept of CE, the open ends are transformed into closed-loops through technologies and recycle of materials (Murray, Skene, & Haynes, 2017; Urbinati, Chiaroni, & Chiesa, 2017; Winans et al., 2017). This system uses and restores waste in order to produce:

Figure 2. The dairy processing



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- materials e.g. using whey as an ingredient to produce cheese
- energy via the transformation of biomass into biofuel, electricity or heat
- water through wastewater management and
- feed for the livestock either directly (with the use of unneeded products and whey), or indirectly (by using it as a fertilizer)

In the case of the use of waste indirectly for the livestock nourishment, the chemicals needed as fertilizer or soil-amendment are reduced, possibly decreasing the business' expenses, while protecting the aquifer and reducing the waste produced from the packaging of such chemical substances.

As a result, the system's inputs and outputs are minimized, creating a more productive, sustainable and self-sufficient system where the produced waste is reduced or/and transformed into other products, by-products and co-products. In the following sections and subsections, a classification of relevant literature on technologies that can be implemented in the realms of the CE concept - according to the stage of the dairy supply chain as shown in Figure 1 - will be presented and analyzed.

Milk Production and Processing of Dairy Products

Anaerobic Digestion

Anaerobic digestion(AD) is the key element in a developing Circular Economy (European Biomass Association (EBA), 2015). First the manure, slurry or wastewater is being collected and placed pasteurized in a pre-storage tank in order to be used by the anaerobic digester, where in absence of oxygen and with the aid of its bacteria, the organic matter is broken down. This process results in two products: the biogas and the digestate (Mason & Burns, 2017).

Biogas can be used to produce electricity and/or heat or as a transport fuel. One of the most common uses is combined heat and power generation (CHP), resulting in electric power and hot water (Kılkış & Kılkış, 2017), which can be used by the farm's and the plant's facilities. There is also a possibility for the biogas to be fed into the natural gas system of the area after meeting certain standards (Kaltschmitt, Thrän, & Smith, 2003), while part of the heat can be reused from the anaerobic digestor, the stables and the factory. Biogas can also be used as a transport fuel and when enriched with CH4 it is a renewable biofuel with a competitive edge (Murphy & Power, 2006).

In the case of animal manure, for the production of energy, AD is preferable due to their high moisture (Gomez, Zubizarreta, Rodrigues, Dopazo, & Fueyo, 2010). For wastewaters from cheese processing, many researchers consider AD as the only method that is sustainable, while some suggest the use of another anaerobic treatment: the Upflow Anaerobic Sludge Blanket (UASB) reactors that can be applied to cheese whey wastewater whether it is diluted or not (Carvalho, Prazeres, & Rivas, 2013). This type of wastewater has a difficult composition due to the whey and cannot be easily processed.

Direct Combustion

Direct Combustion is the process of burning biomass without prior treatment, producing gases in high temperatures (Mckendry, 2002a). Although different types of biomass can be burned, a moisture content of less than 50% is essential, although biomass can be pre-dried (Iakovou, Karagiannidis, Vlachos, Toka, & Malamakis, 2010). The released heat has a number of applications; it can be used on the spot or be

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transported to another place of consumption as heat or be converted with a combined heat and power process (CHP) (Kaltschmitt et al., 2003).

Gasification

During gasification, biomass is converted to a gaseous fuel called synthesis gas (better known as syngas) by thermal decomposition in a limited oxygen environment (Kaltschmitt et al., 2003; Prapaspongsa, Poulsen, Hansen, & Christensen, 2010; Wu, 2013). It can produce two types of gas, Low Energy Gas and Medium Energy Gas which can result into different products, e.g. heat, steam, electricity, fuel gases, used for Internal Combustion Engines (Mckendry, 2002a) .

There are two basic types of gasifiers; the fixed bed and fluidized bed. The fixed bed method relies upon gravity for the feed of biomass, which slowly moves downward surpassing the mentioned above stages (Kaltschmitt et al., 2003). The biomass is (a) dried to remove moisture, (b) devolatilized (pyrolysis) resulting in tar gases, (c) combusted at around 1000 °C depending on the type of the gasifier producing carbon dioxide and heat, and while the hot gases pass upwards they are (d) reduced and hot gas leaves the system (Mckendry, 2002b). The issues with this gasifier are the bad temperature distribution, the time it needs to process and the high costs (Warnecke, 2000).

In the case of fluidized bed gasifiers, the temperature rise increases the produced gas and energy in general. The reactor is open ended and as the name suggests, the bed consists of a fluid material, such as sand or soil (Wu, 2013).

Pyrolysis

Pyrolysis is the process of decomposing biomass and breaking down the matter into smaller molecules in total absence or in a limited supply of air, producing gases, bio-char and bio-oil that can be used as a biofuel (Basu, 2018). Pyrolysis is also a part of other processes e.g. gasification (Mckendry, 2002b). There are also different types of pyrolysis' reactors, the most important being according to Nachenius, Ronsse, Venderbosch, & Prins (2013):

- **Fast pyrolysis Reactors:** in this case, the heating rates are high, the vapor residence time is low and the temperature is around 500 °C, producing bio-oil (Bridgwater, 1999; Sharma, Pareek, & Zhang, 2015).
- **Slow pyrolysis Reactors:** as the name suggests, this technology has significantly lower rates compared to fast pyrolysis, while it takes place at similar temperatures and produces mainly char and tar (Fahmy, Fahmy, Mobarak, El-Sakhawy, & Abou-Zeid, 2018)
- **Torrefaction Reactors:** these reactors convert the biomass at a much lower temperature ranging between 200-300 °C and can produce a high quality biofuel (van der Stelt, Gerhauser, Kiel, & Ptasinski, 2011).

Pyrolysis Coupled With AD

During the AD, a lot of the heat converted which is produced by the CHP system along with electricity is being lost due to the location of the farms, as they are usually isolated (Monlau, Sambusiti, Antoniou, Barakat, & Zabaniotou, 2015), thus it not as easily transportable near residential areas. At the same time,

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solid digestate from the anaerobic process is mostly used as a fertilizer (El-Mashad & Zhang, 2010; Tambone et al., 2010) or biofertilizer (Nizami et al., 2017; Stiles et al., 2018) with applications on-site (Ghisellini et al., 2014).

However, in order to intensify energy recovery from biomass and manure, Monlau et al. (2015) decided to use the produced digestate as a fuel for pyrolysis. The system is designed to take advantage of the produced heat from the CHP system that was untapped in order to dry out the digestate form AD, resulting in a solid digestate that can be used in Pyrolysis. With this method, syngas, bio-oil and bio-char were produced. The first two can be used for electrical production and the latter as a soil amendment.

The results were an increase of 42% in the produced kWh from the coupling of AD and Pyrolysis compared to stand-alone AD. Another benefit is that the bio-char can be used in the soil, which due to its composition of highly stable carbon (Hübner & Mumme, 2015; Monlau et al., 2016) which is a means of natural storage, thus further helping the environment by protecting it from the atmospheric Carbon Dioxide. Bio-char can also be used as a bio-absorbent, i.e. as a detoxifier of lignocellulosic hydrolysate, mainly from furans, in order for them to be used as biofuels (Monlau, Sambusiti, Antoniou, Zabaniotou, et al., 2015).

Wastewater Treatments

Wastewater is one of the most important wastes produced during dairy processing. Wastewater treatments can result not clean water that can be used again in the industry or the farm. Slavov (2017), outlines three types of wastewater:

- **Processing Wastewater:** This category mainly includes the wastewater produced from the cooling and drying procedures of dairy products.
- **Cleaning Wastewater:** As the name suggests, this wastewater is usually the water used to clean equipment that was in contact with the milk or other dairy products.
- **Sanitary Wastewater:** This is like the municipal wastewater and can be treated as such.

Depending on the type of wastewater and its consistency, different treatments are advised. Examples of such treatments are presented in the following subsections.

Discharge to the Municipal Sewage Treatment

Municipal Sewage Treatment facilities are the ones treating wastewater from municipal waste but can treat certain amount of organic substances (Britz, van Schalkwyk, & Hung, 2006). However, although sanitary wastewater is similar to municipal wastewater and is often directly connected to the same sewage treatment plant (Kolev Slavov, 2017), for cleaning and processing dairy wastewater that is not always the case, thus pre-treatment is often advised.

Reverse Osmosis

Reverse Osmosis (RO) for water treatment is a process where a membrane collects and rejects particulates dissolved in the water which is pressured through said membrane (Malaeb & Ayoub, 2011) RO treatment of the dairy wastewaters can produce water that can be used by the processing facilities as well as a milk-

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based by-product that can be used for dairy products e.g. dulce de leche (Brião, Vieira Salla, Miorando, Hemkemeier, & Cadore Favaretto, 2019). Vourch, Balannec, Chaufer, & Dorange (2008) consider that an extra stage of RO could be added to achieve drinking water requirements to the 11 French dairy plants they investigated. Thus, depending on the method of RO, the facility can retrieve water of satisfactory quality for the processing facilities or consumption and components for dairy products.

Aerobic Processes

Aerobic processes, unlike the anaerobic, take place in the presence of oxygen. In this case there are aerobic micro-organisms that break down organic matter such as manure, wastewaters and other types of biomass. Different types of aerobic processes exist and are applicable in the case of the production of dairy products.

Aerobic Composting

The aerobic composting process starts by piling the organic matter, whose temperature increases as micro-organisms are metabolizing the matter, and is followed by a "curing stage", where temperature decreases. In the end, the material becomes darker and more soil-like (Misra, Roy, & Hiraoka, 2003). Passive composting is also a very common practice, where the organic waste is simply left to compost over a long period of time with slow aeration rate.

In the case of dairy farms, this technology can be utilized mainly for the animal manure. It is important to state here that passive composting has been a common practice for many years as in farms manure is being directly used as a fertilizer.

Activated Sludge Process (ASP)

This method is applicable to both industrial and domestic wastewaters, is space-saving and results in a satisfactory quality outflow (von Sperling, 2007). The inflow originates from the primary treatment, where the wastewater enters and the first sludge is removed (Ahansazan, Afrashteh, Ahansazan, & Ahansazan, 2014). According to van Sperling (2007), in the aeriation tank the biochemical reaction takes place in the presence of oxygen and with the growth of organisms such as bacteria, fungi and protozoa (Bhargava, 2016). Afterwards, the secondary sedimentation tank is where the solid biomass settles, and the remaining wastewater is the clarified effluent. The biomass is recirculated where feasible, acting as a new influent to the system, while the unusable sludge will be treated in the sludge treatment stage.

This process is important for the treatment of wastewater from the factory is of dairy products, the farm or a slaughterhouse. The result is reusable water, which can be repurposed in the farm or factory operations, while the reuse of the secondary sludge in the aereation is in accordance to the principles of CE. Further looking into the treatment or use of the excess sludge is necessary in order to make it more sustainable.

Dairy Wastewater Treatment Using Water Treatment Sludge as Coagulant

In a study using synthetic dairy wastewater, Suman, Tarique, & Kafeel (2018) attempt to utilize waste and residue for water treatment plants in order to process wastewaters from dairy. This resulted in significant

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removal of pollutants and turbidity, proving that at the same time dairy wastewater can be treated and sludge from the water treatment plants can be disposed.

Marketing/Consuming

At the last stage of the dairy supply chain, the product has been transported to the wholesalers who then sell the dairy goods to supermarkets, foodservice suppliers, restaurants and hotels in order for them to be bought and/or consumed by the final customer. During this process, both organic and inorganic waste is generated and should be treated. Thus, although in the supply chain of dairy products the main products are all the dairy products, by-products and co-products, there is also the packaging, which in many cases is excessive and usually plastic. In the concept of CE both types of waste should be treated.

Dealing With the Organic Waste

In the case of the wholesalers and the retailers, the expired or spoiled products are the main source of waste (Nizami et al., 2017). A possibility is the return of said products to the dairy processing facility in order to be treated like the onsite remaining products, i.e. as organic waste, or to produce other dairy products. However, this solution is not viable in the case of bigger supply chains, as transportation uses resources and pollutes the environment. In those cases, marketing strategies may be adopted e.g. lowering the prices of products that are close to be out-of-date in order to avoid having to throw away these products.

The consumer may have a similar waste profile; however alternative measures are advised. The usual routes to the household organic waste are (a) the sewer, (b) curbside collection of residual waste, (c) food waste collections, (d) home composting and (e) using it as feed for their pets (Parfitt, Barthel, & Macnaughton, 2010). From these methods of discarding waste, food waste collections, home composting and use of it as pet food are sustainable practices and in accordance to the CE principles since they restore natural resources, thus preserving and enhancing the natural capital (Ellen MacArthur Foundation & McKinsey Center for Business and Environment, 2015).

Packaging

As with most products, packaging is a part of the dairy supply chain, whether it is bought in bulk, e.g. cheese from a cheese shop, or pre-packaged e.g. from the fridges at the supermarket. Over the past few years, the reduction, the weight, the recyclability and the renewability of packaging has gathered interest (Vasilaki, Katsou, Ponsá, & Colón, 2016). The amount of packaging of products is proportionate to the dairy product's environmental impact (Finnegan, Goggins, & Zhan, 2018), thus the packaging plays an important role to the sustainability and the environmental profile of the product. At the same time, the quality and type of packaging affects the food security and shelf life of the product which should not be compromised (Conte, Cappelletti, Nicoletti, Russo, & Nobile, 2015), as it affects the human health and can produce waste i.e. the product will be thrown away and be wasted if due to the incorrect packaging it gets spoiled.

To that end, a strategic design of the supply chain in terms of packaging is necessary for dairy products. In the literature review, there are two categories of packaging that are in harmony with the CE principles:

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- **Recyclable Packaging**: In this category different types of packaging are suggested depending on the product: glass bottles (which are 100% and indefinitely recyclable), aluminum caps, polyethylene labels, polystyrene caps, cartons (Vasilaki et al., 2016), complete propylene, tin or carton and polyethylene (Conte et al., 2015) are only some of the types of packaging found in the bibliography. It is also important to point out that, when sold to the wholesalers, the shops and eating establishments, they are usually in cardboard boxes and/or plastic protective films to be easily transported. Plastics, cardboard and glass can be recycled (Vasilaki et al., 2016), while thinner products are more sustainable (Conte et al., 2015), thus during package design they both recyclability and thickness of the material should be taken into account.
- **Biobased Packaging**: During the past few years, bio based materials for limited shelf-life products have been introduced and research, product development and investments on biopolymers have made (Jacobsen, Holm, & Mortensen, 2008). Biobased packaging is renewable and sometimes compostable and can be a solution on waste management issues from disposable packaging and can represent a CE system on its own (Casarejos, Bastos, Rufin, & Frota, 2018).

SOLUTIONS AND RECOMMENDATIONS

In the previous section, the technological and strategical solutions that can help design a dairy supply chain from a CE perspective by closing the open ends and creating a closed loop system were analyzed based on the stage they can be applied at. In Figure 3, the desired system is presented.

As shown in Figure 3, the dairy supply chain from a CE perspective, based on Figure 1 and maintaining the same four categories has new product and material flows. The waste created during the Processing/Manufacturing stage, often combined with the dairy waste created during the consumption period, can be used to produce energy, water and fertilizer using the technologies of the previous section of this chapter. This results in less inputs for the system during the production stage, both for animal feed production and the farm, thus creating a more sustainable and self-sufficient supply system.

During the Distribution and Marketing period, waste can be divided to dairy waste and packaging waste. Dairy waste can be processed along with the waste created during the previous stage, as mentioned above. Packaging can recycled or be biodegradable when possible in order to reduce pollution.

During the Processing/Manufacturing stage, Dairy Processing produces waste which can be divided into four categories in order of preference in a CE Framework:

1. Reusable: this category includes all the products, co-products and by-products that can be reintroduced as materials in order to produce products.
2. Suitable for energy or water production: biomass and wastewaters can be treated through a vast number of technologies to produce energy e.g. through A.D. or provide usable water. This energy and water can be used by the facilities or the farm.
3. Treatable: the materials and wastewaters that cannot be treated for energy should be processed in order to be environmentally safe e.g. with wastewater management.
4. Untreatable: in the end, there are materials that cannot be otherwise treated and have to be discarded.

During the Distribution and Marketing Stage, the waste is produced from Packaging and from Products that are out of date or thrown away:

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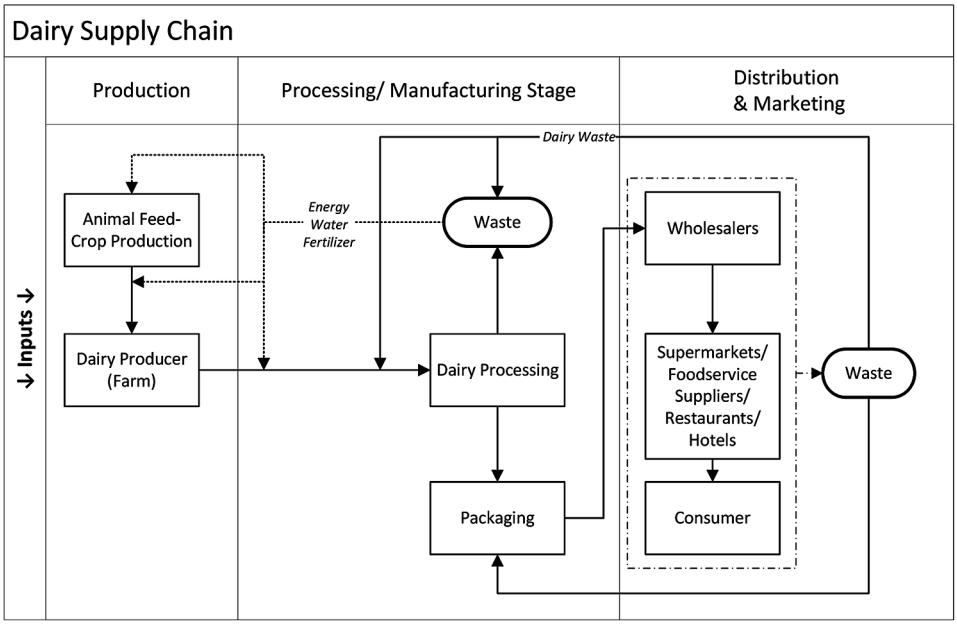
Figure 3. A CE perspective of the dairy supply chain



1. Packaging: the dairy products are packaged both to be bought from the consumer as well as to be transported to be sold in bulk. During the product design, the company should aim to the minimization, recyclability and renewability/biodegradability/compostability of packaging when possible. Informing the shoppers on how to properly recycle or bring the packaging back to the sellers for reimbursement in the case of returnable packaging, e.g. glass milk bottles, is also necessary to ensure optimal results.
2. Wasted Dairy Products: The dairy waste produced from the sellers (whether they are wholesalers, retailers or eating establishments) should be minimized. Two possible strategies are:
    a. Selling the products close to the expiration date at a lower cost to attract more customers.
    b. Giving the products close to the expiration date to organizations thus demonstrating social responsibility.

If none of the above choices are eligible, the remaining products can be sent back to the processing facilities to produce other products or be treated along with the facility's waste.

FUTURE RESEARCH DIRECTIONS

The CE concept is an emerging topic over the past few years due to the irrational use of Earth's natural capital causing resource depletion, especially after World War II. In combination with the projections of International Organisms that show a sharp increase of the world population by the year 2050, which will lead to the need of more land, food and water, the CE concept is for many the sustainable solution to a possible socio-economic crisis on the rise, thus recently it has been thoroughly studied by many researchers, companies and countries.

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At this point, sustainability, waste management, closed-loop models and practices have been more thoroughly investigated and applied in businesses. At the same time, applications of CE in supply chains are minimal, due to the fact that the term is relatively new. In the case of agro-food supply chains and especially dairy supply chains, there are only a few recorded cases. In the future, such models should be designed, simulated and applied in order to optimize the performance and circularity of supply chains. With the progress of technology, more solutions can be developed in order to provide greener, more efficient and lower cost CE solutions.

CONCLUSION

The pressing need to resolve the emerging environmental issues has led researchers, businesses, organizations and countries to search for solutions that can balance the protection of the environment and the satisfaction of people's wants and needs. This has created the sustainability concept, which has been in the center of attention for over 20 years. There are many papers theoretical frameworks as well as implementation examples of sustainable supply chains, sustainable design and development and sustainable business practices; the research however is far from over.

More recently, CE has emerged as sustainability's successor and has received a lot of attention, especially in the European Union and China. Many researchers see similarities between the two concepts since they are both aiming to the protect the environment. However, in bibliography CE is applied specifically by closing the loops of the overall supply chain of a product and applying the 4R framework i.e. "reducing, reusing, recycling and recovering" the waste in the supply chain.

At the same time, world population is continuously rising and thus issues with food and water security arise. In order to cover the increased needs is a sustainable way, CE principles can be applied on agri-food supply chains. This chapter focuses on a category of products of wide consumption; the dairy products. This particular supply chain consists of a variety of products, with different consistencies, shelf lives and temperatures of storage, that are produced from various types and sizes of businesses. In order to close the loops, there are several different technologies and available strategies.

During the production stage, where the raw material i.e. milk is produced, and the processing/manufacturing stage, there are alternative ways to treat biomass in order to produce energy, fertilizer, with AD getting most commonly mentioned, and materials that can make other products, by-products and co-products. Wastewater treatment is also an important procedure which can provide the supply chain with water and extra biomass. During the marketing and consuming stage, the main source of waste is packaging, which in a CE should be recycled; thus, when designing such a supply chain the amount of packaging as well as it recyclability, reusability or biodegradability should be taken into consideration during the product's design and the consumer should be informed on how to appropriately dispose of it. However, during this stage there is leftover product that either expires or gets spoiled. To avoid this, close-to-expire products should be sold at a lower price or made available to humanitarian organizations, while the rest should be treated as biomass.

In conclusion, although in theory there are many technological and strategical solutions applicable from a CE perspective on the dairy supply chain, in practice there are not many examples of such applications which constitutes a real challenge. In the future, the design, simulation and implementation of such practices is necessary as different combinations of technologies could bring different results, while the technological evolution could bring new solutions. At the same time, further research on waste

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management and in particular biomass management and packaging materials is necessary. Following these recommendations could further improve and optimize CE and the dairy supply chain.

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KEY TERMS AND DEFINITIONS

Anaerobic Digestion: A process where in absence of oxygen and with the aid of its bacteria, the organic matter is broken down, resulting in biogas and digestate.

Bioenergy: The energy produces by processing the biomass.

Biomass: Organic matter that is usually used for energy production.

Circular Agriculture: The circular economy concept applied in agriculture.

Manure Management: The collection, storage, and processing of manure in order to provide mainly energy and fertilizer.

Wastewater Management: The processing of wastewater in order to be suitable to be discharged back to the environment or reused.

Whey: The effluent at the end of milk production which can be used as a product or be used for the production of other dairy products.

Whey Management: The storage and treatment of whey in order to provide new products or be processed as biomass.

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Chapter 5
Benchmarking Sustainability Performance of Organizations Using a Multicriteria Approach With Application to Canadian Market

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ABSTRACT

In this chapter, the authors propose a multi-criteria framework for benchmarking sustainability performance of organizations. The indicators for evaluation are obtained using sustainalytics database. Multicriteria decision making technique called TOPSIS (Technique for Ordered Preference by Similarity to Ideal Solution) is used to generate organization rankings. The proposed technique is applied to evaluate performance of 24 companies in two major sectors: manufacturing and service. The selected companies come from the Canadian market. The results of TOPSIS study show manufacturing sector to be doing better than the service sector with average relative closeness (Ci) of 0.5 and 0.36, respectively. Future work can involve integration of financial KPIs, cross-sector investigation and involvement of MCDM techniques such as AHP for weighting in the proposed study.

INTRODUCTION

Sustainability is about improving our standard of living by protecting human health, conserving the environment, using resources efficiently and advancing long-term economic competitiveness (Sustainable Development, 2017).

There is no doubt extra costs occur when organizations start the transformation towards implementing green strategies. Regardless of the ultimate propose of the green initiatives companies are undertaking, adoption of green/sustainable practices may initially result in reduction of financial benefits, increasing

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the processing costs and slowing down the market growth. However, once the environmental management system is well developed, long term benefits along with several business advantages may compensate the initial cost.

As Pryce (2002) puts it, five major elements exert pressure on organizations to engage them in more socially and environmentally conscious operations. These factors are: customer pressure, changes in business procurement, government legislation and pressure, the rise of socially responsible investment, and the changing expectations of employees.

Depending upon the organizational culture, the process of incorporating the aforementioned drivers into strategic sustainability behavior encounters different responses including: resistant, reactive, anticipatory, and innovation-based to sustainability-rooted (Klewitz & Hansen, 2014). Unless it is truly part of the fundamentals of a corporate strategy, corporate social responsibility has no real meaning for an organization. Many initiatives have been put forth by organizations in this regard. For example, green design, green procurement, green production, green distribution and warehousing, and reverse logistics etc. These initiatives have not only helped achieve environmental goals but also assisted in business performance improvement and gaining competitive edge in the market.

Therefore, organizations are more and more interested in developing their sustainability performance. Sustainability performance measurement meets this need by providing corporations with information needed to help in the short and long-term management, controlling, planning, and performance of the economic, environmental, and social activities carried out by the corporation (Medel-González et al., 2016). A critical element of this activity is identification of measurement metrics that synchronizes the organizational effort towards sustainable development. GRI (Global Reporting Initiative), DJ (Dow Jones), CK (Corporate Knights) and Sustainalytics are examples of few initiatives who provide a comprehensive set of Key Performance Indicators for corporate sustainability measurement.

The goal of the authors in this research paper is to develop a framework for benchmarking sustainability performance of organizations. This involves:

- Identification of KPIs, criteria or indicators for measuring sustainability performance of organizations.
- Development of a benchmarking model based on a multi-criteria framework and the selected KPIs to rank the sustainability performance of organizations.
- Execution of the benchmarking model using real data for manufacturing and service sector companies based on Canadian market and generate recommendations. (Awasthi, et al., 2010); (Awasthi, et al., 2016); (Awasthi, et al., 2018); (Gold & Awasthi, 2015).

The rest of the paper is organized as follows. Section 2 presents the literature review. The solution approach is presented in section 3 followed by numerical application in section 4. Finally, the conclusions and future works complete the paper in section 5.

LITERATURE REVIEW

As first outlined by Kaplan and Norton in 1992, the Balanced Scorecard (BSC), is a strategic management tool to both operationalize and measure strategies of a company or its units (usually strategic business units), but may also be used as a comprehensive management system which cascades down

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from the administrative level, over business units and functions, to individuals, by means of incentive and compensation schemes (Kaplan & Norton, 2005); (Hansen & Schaltegger, 2016). The BSC's four perspectives may be summarized as (Figge et al., 2002b):

- Financial perspective
- Customer perspective
- Internal process perspective
- Learning and growth perspective

There are essentially three ways to incorporate environmental and social aspects into the BSC. Firstly, the existing four standard perspectives can incorporate new environmental or social factors. Secondly, it can be supplemented with new perspectives, to take into account different environmental and social aspects. Thirdly, a new scorecard can be formulated for a particular environmental and/or social aspect (Figge et al., 2002b) as follows.

- Integration of environmental and social aspects in the four standard perspectives
- Introduction of an additional non-market perspective into the Balanced Scorecard
- Deduction of a derived environmental and social scorecard

Corporations may see various gains from the application of a SBSC framework, which will differ depending on their function. Some of them strengthen the reporting process (see Table 1) (Tsalis et al., 2015).

Table 1. Frameworks based on SBSC

Studies	Purpose of the SBSC Framework	Framework's Articulation	Expected Contribution
Sidiropoulos *et al.,* (2004)	Strategic Management	Five Perspectives	Improvements in marketing and in implementing of the sustainability strategy
Laurinkevičiūtė, Kinderytė, Stasiškienė, (2008)	Strategic Management	Four Perspectives	Improvements in the decision-making process
Yongvanich and Guthrie (2006)	Reporting Purpose	Three Basic Structures	Improvements in reporting of sustainable performance and in internal process
Thanaraksakul and Phruksaphanrat (2009)	Suppliers Evaluation	Five Perspectives	Better evaluation of potential suppliers
Moreo, DeMicco, and Xiong (2009)	Strategic Management	Five Perspectives	Improvements in understanding the role of environmental goals in corporate strategy
Panayiotou, Aravossis, and Moschou (2009)	Measurement of Sustainability Performance	Four Perspectives	Improvements in measurement of CSR performance
Hsu *et al.,* (2011)	Measurement of Sustainability Performance	Four Perspectives	Improvements in addressing and measurement of sustainable performance
Van der Woerd and Van den Brink (2004)	Strategic Management	Five Perspectives	Improvements in implementation of sustainable strategy
Tsai, Chou, and Hsu (2009)	SRI	Four Perspectives	Improvements in evaluation of SRI
Hubbard (2009)	Measurement of Sustainability Performance	Six Perspectives	Improvements in measurement and in reporting of corporate sustainable performance
Leon-Soriano, Muñoz-Torres, and Chalmeta-Rosaleñ (2010)	Strategic Management	Three Perspectives	Improvements in strategic planning and management
Wu and Liu (2010)	Performance Measurement	Five Perspectives	Better evaluation of ISO 14001 certified industries

Source: (Tsalis et al., 2015)

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To develop SBSC, it was needed to define Key Performance Indicators (KPIs) which helps define and measure progress toward organizational goals and objectives. When a company has examined its mission and defined its objectives, it must next measure its progress towards those objectives. KPIs serve as a tool for such measurement. They help a company determine whether it is 'on track' –that it is working towards and attaining a beneficial outcome or improvement. In many circumstances, companies use KPIs in projects and to measure service delivery (APM).

Many international initiatives have focused on sustainability indicators at different scales: global, national, regional, supply chain, company, factory, and process and product scope, with the goal of supplying the relevant information to various decision-making levels (Fantini, Palasciano, & Taisch, 2015). There are many examples of developed sustainability indicators; both general and sector-specific (see Table 2). The primary concern with these indicator frameworks is that generally the spotlight is on the external reporting for stakeholders, rather than on internal information needed to make decisions and to revise or optimize for ecological innovation. Manufacturers in this situation need a standardized framework for the sustainable manufacturing environment, where they can easily evaluate and track their sustainability performance (Feng & Joung, 2009).

Table 2. Various sustainability indicators and metrics

Indicator Set	Components	Reference
Global Report Initiative (GRI)	70 Indicators	http://www.globalreporting.org/ReportingFramework/ReportingFrameworkDownloads/
Dow Jones Sustainability Index (DJSI)	12 Criteria Based Single Indicator	http://www.sustainabilityindex.com/07_htmle/publications/guidebooks.html
2005 Environmental Sustainability Indicators	76 Building Blocks	http://www.yale.edu/esi/ESI2005.pdf
2006 Environment Performance Indicators	19 Indicators	http://sedac.ciesin.columbia.edu/es/epi/downloads/2006EPI_Report_Full.pdf
United Nations Committee on Sustainable Development Indicators	50 Indicators	http://www.un.org/esa/sustdev/natlinfo/indicators/guidelines.pdf
OECD Core Indicators	46 Indicators	http://www.oecdbookshop.org/oecd/display.asp?sf1=identifiers&st1=972000111E1
Indicator Database	409 Indicators	http://www.Sustainablemeasures.com
Ford Product Sustainability Index	8 Indicators	http://www.ford.com/doc/sr07-ford-psi.pdf
GM Metrics for Sustainable Manufacturing	46 Metrics	http://actionlearning.mit.edu/slab/files/slab_files/Projects/2009/GM,%20report.pdf
ISO 14031 Environmental Performance Evaluation	155 Example Indicators	http://www.iso.org/iso/iso_catalogue/catalogue_ics/catalogue_ics_browse.htm?ICS1=13&ICS2=20&ICS3=10
Wal-Mart Sustainability Product Index	15 Questions	http://walmartstores.com/download/3863.pdf
Environmental Indicators for European Union	60 Indicators	http://biogov.cpdr.ucl.ac.be/communication/papers/tepi99rp_EN105.pdf
Eco-Indicators 1999	3 Main Factors Based Single Indicator	http://www.pre.nl/eco-indicator99/ei99-reports.htm

Source: (Feng & Joung, 2009)

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Worthwhile critiques of the BSC concept point out that there is no causal link between the measures from these four perspectives. In particular, there is no causal link between the measures with regard to sustainable development strategy, either (Tsai & Chou, 2009).

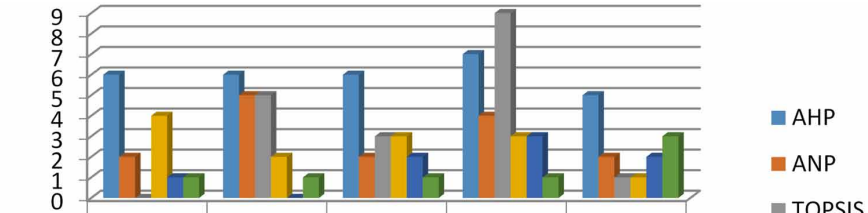
Although there are a multitude of potential gains for companies which adopt the SBSC, it has some shortcomings, resulting from the nature of the conventional BSC concept. Such deficiencies are essentially a reflection of the BSC's incapacity to account for the dynamic and complex aspects of a company's situation that influence the implementation of their strategies (Tsalis et al., 2015).

Decision making (DM) methods can assist in linking the measures to sustainable development strategy. 26 decision making (DM) techniques are identified from three perspectives: (1) Multicriteria decision making (MCDM) techniques, (2) Mathematical programming (MP) techniques, and (3) Artificial intelligence (AI) techniques (Chai, Liu, & Ngai, 2013). MCDM is the most well-known branch of decision making (Mardani et al., 2015). It can be classified them into four categories:

1. Multiattribute utility methods such as AHP and ANP
2. Outranking methods such as Elimination and Choice Expressing Reality (ELECTRE) and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE)
3. Compromise methods such as Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) and Multicriteria Optimization and Compromise Solution (VIKOR)
4. Other MCDM techniques such as Simple Multiattribute Rating Technique (SMART) and Decision-Making Trial and Evaluation Laboratory (DEMATEL) and Data Envelopment Analysis (DEA) (Chai et al., 2013).

The distribution of a few of the major decision-making processes that appeared during the period 2008-12 is illustrated in Figure 1. Multi-attribute utility methods, including AHP and ANP, overshadow other techniques because of their effectiveness in ranking tasks and choices. TOPSIS and DEA remain significant in the construction of decision models. Considerable research attention is also being devoted to AI techniques, such as GA and GST (Chai et al., 2013).

Figure 1. Chronological Distribution of Some Major DM Techniques – Source: Chai er al., 2013
Source: (Chai et al., 2013)



	2008	2009	2010	2011	2012
AHP	6	6	6	7	5
ANP	2	5	2	4	2
TOPSIS	0	5	3	9	1
DEA	4	2	3	3	1
GA	1	0	2	3	2
GST	1	1	1	1	3

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Table 3. Applied papers in "Health, Safety and Environment Management"

Author (s)	Specific Area	Other Techniques Combined or Compared	Group Decision Making
Aiello, Enea, Galante, and La Scalia (2009)	Selecting the most suitable extinguisher ozone- depleting substance	Fuzzy TOPSIS and AHP	
Berger (2006)	Generating depictions of the agricultural landscape for use in alternative future scenario modeling	–	
Chen, Blong, and Jacobson (2001)	Determining priority areas for a bushfire hazard reduction burning	Compromise programming and weighted linear combination	
Cheng, Chan, and Huang (2003)	Selecting landfill locations in the solid waste management problem	Inexact mixed integer linear programming, simple weighted addition, weighted product, co-operative game theory, and complementary ELECTRE	
Ekmekçioglu, Kaya, and Kahraman (2010)	Selecting appropriate disposal methods and sites for municipal solid waste	Fuzzy TOPSIS and fuzzy AHP	
Grassi, Gamberini, Mora, and Rimini (2009)	Evaluating risk involved in hazardous activities of the production process of a well-known Italian sausage	Fuzzy TOPSIS	
Gumus (2009)	Selecting the right and most appropriate hazardous waste transportation firm	Fuzzy AHP and Delphi method Multi-objective	•
Han, Jia, and Tan (2003)	Selecting the best compromise solution for process environmental performance assessment	Multi-objective optimization, NSGA-II and AHP	
Huang, Zhang, Liu, and Sutherland (2011)	Environmentally conscious materials selection problem	Uncertainty analysis	
Kabak and Ruan (2010)	Nuclear safeguard evaluation for using nuclear programs for nuclear weapons purposes	SAW, Non-compensatory method, and fuzzy approach	
Krohling and Campanharo (2011)	Selecting the best alternatives to manage oil spill accidents in the sea in Brazil	Fuzzy TOPSIS	•
Li, Zhang, Zhang, and Suzuki (2009b)	Identifying the set of optimal parameters to design and optimize chemical processes based on green chemical principles	Multi-objective mixed integer non-linear mathematical model and NSGA-II	
Liu, Frazier, Kumar, Macgregor, and Blake (2006)	Assessing wetland conditions in the Clarence River Catchmen	–	
Olcer and Majumder (2006)	Selecting the set of counter-flooding tanks to achieve an optimal response to a flooding accident	–	
Onut and Soner (2008)	Solid waste transshipment site selection problem	Fuzzy AHP and fuzzy TOPSIS	
Rao and Baral (2011)	Evaluating available waste combinations and selecting the best waste combination	–	
Sadeghzadeh and Salehi (2011)	Ranking development alternatives based on eight technologies of accumulated fuel cells	–	
Shi, Xu, and Li (2009)	Evaluating and prioritizing the ecological revetment projects	Delphi-AHP method and fuzzy TOPSIS	
Simonovic and Verma (2008)	Waste water treatment planning problem	Fuzzy pareto optimal solution set	
Sivapirakasam *et al.,* (2011)	Selecting process parameters to achieve green electrical discharge machining	Taguchi method and fuzzy TOPSIS	
Soltanmohammadi, Osanloo, and Aghajani Bazzazi (2010)	Determining a preference order of post-mining land uses	AHP	•
Tzeng, Lin, and Opricovic (2005)	Evaluating buses with alternative fuels for public transportation to improve environmental quality	AHP and VIKOR	•
Vahdani, Zandieh, and Tavakkoli-Moghaddam (2011b)	Determining appropriate fuel buses	Fuzzy TOPSIS	•
Wang, Fan, and Wang (2010)	Rating candidate aero engines for the aero engine health assessment problem	Fuzzy AHP and fuzzy preference programming	
Wang and Elhag (2006)	Optimal scheme of bridge structure maintenance problem	Fuzzy TOPSIS and nonlinear programming	
Yue (2011a)	Assessing air quality at the Asian Olympic Games in Guangzhou	Extended TOPSIS with interval numbers	•
Zavadskas and Antucheviciene (2006)	Ranking sustainable revitalization alternatives of derelict rural buildings in Lithuania	Fuzzy TOPSIS	
Zavadskas and Antucheviciene (2004)	Determining redevelopment priorities of buildings (sustainable development approach)	VIKOR	

Source: (Behzadian et al., 2012)

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Table 4. Some Applications of TOPSIS Based on Work of Shih et al. (2007)

Application areas	No. of Attributes	No. of Alternatives	Proposed by
Company financial ratios comparison	4	7	Deng *et al.,* (2000)
Expatriate host country selection	Six major attributes & 25 sub-attributes	10	Chen and Tzeng (2004)
Facility location selection	5	4	Chu (2002)
Gear material selection	5	9	Milani *et al*., (2005)
High-speed transport system selection	15	3	Janic (2003)
Manufacturing plant location analysis	Five major attributes & 16 sub-attributes	5	Yoon and Hwang (1985)
Multiple response selection	2	18	Yang and Chou (2005)
Rapid prototyping-process selection	6	6	Byun and Lee (2005)
Robot selection	4	27	Parkan and Wu (1999)
Solid waste management	12	11	Cheng *et al*., (2002)
Water management	6	12	Srdjevic *et al*., (2004)

Source: (Shih et al. 2007)

Table 3 shows the application of various MCDM methods in the area of Health, Safety and Environment Management.

Among the many MCDA/MCDM methods developed to address concrete decision problems, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) continues to perform satisfactorily in various areas of application, because it has a comprehensible theoretical structure and can provide a precise model for making decisions. It is a well-known classical MCDA/MCDM method that has interested researchers and practitioners. Interest in the method globally has grown exponentially (Huang & Li, 2012).

Behzadian et al. (2012) conducted a survey of 269 papers and found that TOPSIS and its hybrid methods were used by 27.5% papers addressing the theme of Supply Chain Management and Logistics, 23% (Design, Engineering and Manufacturing Systems), 12.3% (Business and Marketing Management), 10.4% (Health, Safety and Environment Management), 8.9% (Human Resources Management), 5.2% (Energy Management), 2.6% (Chemical Engineering), 2.6% (Water Resources Management), and 7.4% (Other topics). Some application areas of TOPSIS based on work of Shih et al. (2007) are shown in Table 4 (Mukherjee, 2014); (Kannan, Pokharel, & Kumar, 2009).

DEA and BSC techniques have also been used by few researchers. Roodposhti et al. (2010), for example, introduce an analytical model for organizational performance evaluation based on DEA and BSC techniques. Ramanathan and Ramanathan (2011) suggest that BSC can be benefit by incorporating DEA. BSC with DEA has been used in the balanced performance evaluation of Health Authorities (HAs) in Great Britain (Arabzad et al., 2013).

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SOLUTION APPROACH

The solution approach involves three main steps:

- Identification of KPIs for benchmarking sustainability performance of organizations considering the initiatives and frameworks related to sustainability studied in literature review.
- Measure and benchmark sustainability performance of organizations using the identified KPIs and TOPSIS technique.
- Compare the results obtained from steps 2 and 3 for manufacturing and service sector organizations and generate recommendations.

These steps are explained in detail as follows:

KPIs Selection for Sustainability Measurement

To identify KPIs for sustainability measurement, different initiatives and frameworks were studied. United Nations Global Compact, World Business Council for Sustainable Development (WBCSD), Earth Charter and ISO are examples of such initiatives and GRI (Global Reporting Initiative), DJSI (Dow Jones Sustainability Index), CK (Corporate Knights) and Sustainalytics are some examples of the frameworks which provide sustainability indicators.

Sustainalytics similar to GRI presents sustainability indicators in three major dimensions: Governance, Environment and Social. In each of the dimensions, several KPI (Key Performance Indicators) are considered. 21 KPIs in Governance, 14 KPIs in Social and 15 KPIs in Environment are used in this research (see Table 5).

Sustainalytics database not only includes very powerful indicators, but also provides the scores and rankings for companies. The access to database was also available through Concordia University Library.

With considering all above mentioned points, the preliminary data of this research is extracted from Sustainalytics database which follows and scores the sustainability performance of companies commonly in United States and Canada. The data was only extracted from the Canadian available industries to focus on Canadian market. A total of 50 KPIs from Sustainalytics database were considered in this research.

Table 6 shows the sustainability KPIs from Sustainalytics chosen for this study. There are three main dimensions: Governance, Social, and Environment.

TOPSIS Method

TOPSIS was introduced by Yoon (1980) and Hwang and Yoon (1981) for solving multiple criteria decision making (MCDM) problems. This methodology centers on the concept that the selected alternative

Table 5. Sustainability Dimensions and Relates KPIs

S. Dimensions	Governance	Social	Environment
Sub-Dimensions No.	3	4	3
KPIs No.	21	14	15

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Table 6. Sustainability Scorecard (SSC)

Sustainability Scorecard		
Governance Score	**Social Score**	**Environment Score**
G.1.1 Bribery & Corruption Policy	S.1.1 Freedom of Association Policy	E.1.1 Environmental Policy
G.1.2 Whistleblower Programmes	S.1.2 Discrimination Policy	E.1.2 Environmental Management System
G.1.3 Global Compact Signatory	S.1.3 Diversity Programmes	E.1.3 EMS Certification
G.1.4 Tax Disclosure	S.1.4 Collective Bargaining Agreements	E.1.4 Environmental Fines & Penalties
G.1.5 Business Ethics Incidents	S.1.5 Employee Turnover Rate	E.1.5 CDP Participation
G.2.1 ESG Reporting Standards	S.1.6 Employee Fatalities	E.1.6 Scope of GHG Reporting
G.2.2 Verification of ESG Reporting	S.1.7 Employee Incidents	E.1.7 GHG Reduction Programme
G.2.3 Board Remuneration Disclosure	S.2.1 Scope of Social Supplier Standards	E.1.8 Renewable Energy Programmes
G.2.4 Board Biographies Disclosure	S.2.2 Supply Chain Monitoring	E.1.9 Carbon Intensity
G.2.5 ESG Governance	S.2.3 Social Supply Chain Incidents	E.1.10 Carbon Intensity Trend
G.2.6 ESG Performance Targets	S.3.2 QMS Certifications	E.1.11 Renewable Energy Use
G.2.7 Gender Diversity of Board	S.3.3 Customer Incidents	E.1.12 Operations Incidents
G.2.8 Separation of Chair & CEO	S.4.1 Activities in Sensitive Countries	E.2.1 Green Procurement Policy
G.2.9 Board Independence	S.4.3 Society & Community Incidents	E.2.2 Environmental Supply Chain Incidents
G.2.10 Audit Committee Independence		E.3.2 Product & Service Incidents
G.2.11 Non-Audit to Audit Fee Ratio		
G.2.12 Compensation Committee Independence		
G.2.13 Governance Incidents		
G.3.1 Political Involvement Policy		
G.3.2 Lobbying and Political Expenses		
G.3.4 Public Policy Incidents		

solution should have the shortest Euclidian distance from the Positive Ideal Solution (PIS) and the farthest from the Negative Ideal Solution (NIS). The positive ideal solution is the solution that maximizes the benefit criteria and minimizes the cost criteria, while the negative ideal solution minimizes the benefit criteria and maximizes the cost criteria. The positive ideal solution is where all criteria are at the best possible value, and the negative ideal solution is where all criteria are at the worst possible value (Kuo, Hsu, & Chen, 2015) ; (Behzadian et al., 2012).

TOPSIS method involves a series of successive steps described as follows (Srikrishna, Sreenivasulu, & Vani, 2014) ; (Huang & Li, 2012) ; (Behzadian *et al.,* 2012):

Step 1: Data Collection

The first step of the TOPSIS method involves the construction of a Decision matrix (D).

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Box 1. Decision matrix

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & & C_n \end{array} \\ \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1n} \\ X_{21} & X_{22} & \cdots & X_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ X_{m1} & X_{m2} & \cdots & X_{mn} \end{bmatrix} \end{array}$$

$$i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n \tag{1}$$

where '*i*' is the criterion index ($i = 1 \ldots m$); and '*j*' is the alternative index ($j = 1 \ldots n$). The elements $C_1, C_2 \ldots, C_n$ refer to the alternative observations; while $A_1, A_2 \ldots,$ and A_m refer to the criteria. The elements of the matrix are related to the values of criteria *i* with respect to alternative *j*.

Step 2: Data Normalization

The Normalized Decision Matrix (NDM) contains the normalized values which represents the transformed values of the alternatives on a common scale. For example, different alternatives may be expressed in different units (e.g., km, kg, m3) and may have different nature (e.g., cost, revenue). Hence, it is important to bring their data to a common scale before the evaluation process through normalization. In literature, a variety of normalization methods have been proposed. For example, vector normalization, linear normalization, non-monotonic normalization (Shih *et al.,*2007). In this study, since, all the alternative values are on common scale (0-100) and have same nature (benefit type), normalization has less impact. To transform the alternative values to a score of (0-1), following normalization formula can been used.

$$NDM = R_{ij=} \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}} \tag{2}$$

Step 3: Determine the Weighted Score Values

Not all of the selection criteria are of equal importance. The weighting decision matrix is constructed by multiplying each element of each column of the normalized decision matrix by its respective criteria weight.

$$V = V_{ij} = R_{ij} * W_j \tag{3}$$

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Step 4: Determine the Positive and Negative Ideal Solution

The positive ideal (*PIS* or A^+) and the negative ideal (*NIS* or A^-) solutions are defined according to the weighted decision matrix via equations (4-5) below:

$$PIS = A^+ = \{V_1^+, V_2^+, \ldots, V_n^+\},$$

where

$$V_j^+ = \{(\max_i (V_{ij}) \text{ if } j \in J); (\min_i V_{ij} \text{ if } j \in J')\} \quad (4)$$

$$NIS = A^- = \{V_1^-, V_2^-, \ldots, V_n^-\},$$

where:

$$V_j^- = \{(\min_i (V_{ij}) \text{ if } j \in J); (\max_i V_{ij} \text{ if } j \in J')\} \quad (5)$$

where, *J* is associated with the beneficial attributes and *J'* is associated with the non-beneficial or cost attributes.

Step 5: Calculate the Separation Measures Using the N-Dimensional Euclidean Distance

Calculate the separation distance of each competitive alternative from ideal solution is given as:

$$S^+ = \sqrt{\sum_{j=1}^{n} \left(V_j^+ - V_{ij}\right)^2} \quad i = 1, \ldots, m \quad (6)$$

Similarly, the separation from the negative ideal solution is given as

$$S^- = \sqrt{\sum_{j=1}^{n} \left(V_j^- - V_{ij}\right)^2} \quad i = 1, \ldots, m \quad (7)$$

where, i = criterion index, j = alternative index.

Step 6: Calculate the Relative Closeness of Each Observation to the Ideal Solution

For each competitive alternative, the relative closeness of the potential location with respect to the ideal solution is computed using the following equation.

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$$C_i = S_i^- / (S_i^+ + S_i^-) , \ 0 \leq C_i \leq 1 \quad (8)$$

Note that $C_i = 0$ when $A_i = A^-$, and $C_i = 1$ when $A_i = A^+$.

Step 7: Rank the Preference Order

The higher the value of the relative closeness C_i, the higher the ranking order, and hence the better the performance of the alternative is. Ranking of C_i in descending order thus allows better comparison of relative performances (Srikrishna *et al.,* 2014) ; (Chang & Hsieh, 2014).

Shih *et al*. (2007) note that TOPSIS is straightforward and suitable for cases with an unlimited range of criteria and performance attributes, especially for use with objective or quantitative data.

APPLICATION RESULTS

Two major sectors (manufacturing and service) from Canadian Market were considered for the study, with each sector having 24 companies organized in 8 categories. The manufacturing categories comprise of Oil & Gas producers, Aerospace & Defense, Auto components, Transportation, Chemicals, Diversified metals, Paper & Forestry, and Precious metals. The service categories comprise of Banks, Diversified financials, Insurance, Media, Telecommunication services, Commercial services, Energy services, and Real estate. The sustainability performance of 24 different companies in each sector was benchmarked against each other to determine their relative scoring. The organization with the highest score (Total ESG Score) was considered to be performing best in terms of sustainability. The criteria used for measuring the sustainability performance are Governance, Social and Environment. In each of the dimensions, several KPI (Key Performance Indicators) are considered. There are 21 KPIs in Governance, 14 KPIs in Social and 15 KPIs in Environment dimension. A total of 50 KPIs were used for evaluation. Table 7 summarizes this information.

In the original Sustainanalytics database, there are more than 50 KPIs, however the authors have limited this study to only 50 for multiple reasons. Firstly, the authors intend to integrate the whole study by using exactly the same KPIs for all companies. Some KPIs were not applicable to all companies. Secondly, many KPIs had non-numerical values, hence they were ignored. Lastly, some of them did not have value and were shown as "No data" in the database. The authors considered zero value for them to give them numerical value to unify the study.

These little changes also affect the cumulative values of each company when compared to the original dataset ranking.

After implementing TOPSIS method on the prepared data, the following results was obtained.

Table 7. Sustainability dimensions and relates KPIs

S. Dimensions	Governance	Social	Environment
Sub-Dimensions No.	3	4	3
KPIs No.	21	14	15

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Ranking the Service Sector Organizations

Table 8 shows TOPSIS calculations for service industries and the resulting rankings. It can be seen that most of the industries are so far from the Ideal Solutions. Only Co. 7.1 in Energy S. presents a good performance with Relative Closeness more than 0.5; or 0.5206 value which receives the first rank. It means there is opportunity to increase the sustainability performance of service industries.

The ranking of each organization (observation) includes 50 criteria and depends on their scores with respect to the maximum and minimum values for that criterion (extracted from 24 observations). For example, Operation Incidents values for ranking 1 and 24 are 12 and 3.5 respectively which also represent maximum and minimum of this criterion. The same pattern can be observed for other KPIs such as CDP Participation criterion. The performance of each observation can be justified by comparing its outputs with maximum and minimum of each criterion.

The histogram of results for service sector is presented in Figure 2.

Table 8. Rankings for service sector companies

No.	Sector	Company No.	S^+	S^-	Relative Closeness Index(Ci)	TOPSIS Ranking
1	Banks (1)	Co. 1.1	14.0698	6.42921	0.31364	18
2		Co. 1.2	14.67017	5.36732	0.26786	24
3		Co. 1.3	14.18167	7.81761	0.35536	9
4	Diversified Financials (2)	Co. 2.1	13.83975	8.55108	0.3819	7
5		Co. 2.2	14.70439	7.33937	0.33295	15
6		Co. 2.3	15.10479	7.08166	0.31919	17
7	Insurance (3)	Co. 3.1	14.05299	7.54236	0.34926	11
8		Co. 3.2	14.43175	6.98247	0.32607	16
9		Co. 3.3	15.18127	6.15005	0.28831	22
10	Media (4)	Co. 4.1	13.22179	9.21815	0.41079	6
11		Co. 4.2	14.78853	8.07903	0.3533	10
12		Co. 4.3	14.9603	7.77147	0.34188	13
13	Telecommunication S. (5)	Co. 5.1	12.8304	6.6673	0.34195	12
14		Co. 5.2	13.39163	5.88509	0.3053	20
15		Co. 5.3	13.40923	6.0832	0.31208	19
16	Commercial S. (6)	Co. 6.1	11.9106	9.31288	0.4388	3
17		Co. 6.2	12.24649	9.15018	0.42764	5
18		Co. 6.3	13.49059	7.47141	0.35643	8
19	Energy S. (7)	Co. 7.1	10.95774	11.8993	0.5206	1
20		Co. 7.2	12.73807	10.3182	0.44752	2
21		Co. 7.3	12.9315	9.87669	0.43303	4
22	Real Estate (8)	Co. 8.1	13.87218	7.16229	0.3405	14
23		Co. 8.2	14.76825	6.05354	0.29073	21
24		Co. 8.3	14.86262	5.98104	0.28695	23

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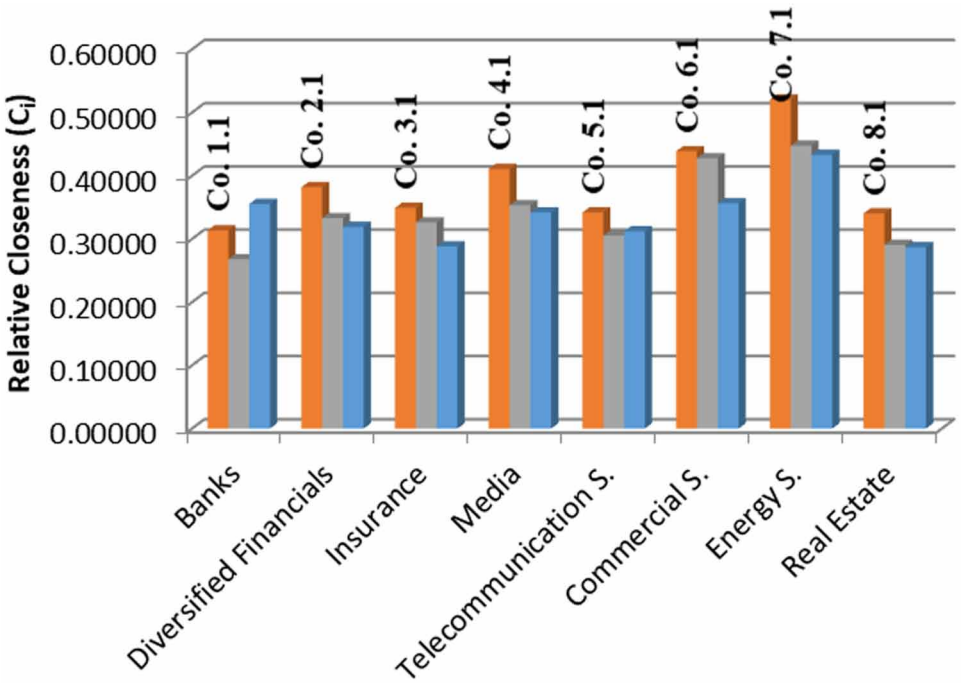
Figure 2. Relative closeness index values (Ci) for service sector companies



Ranking the Manufacturing Sector Organizations

Table 9 shows TOPSIS calculations for manufacturing industries and the resulting rankings. It can be seen that most of the industries are far from the Ideal Solutions. However, many companies present a good performance with Relative Closeness more than 0.5. Co.1.1 in Oil & Gas producers with 0.56256 receives first rank. It means there is opportunity to increase the sustainability performance of manufacturing Industries.

The ranking of each observation includes 50 criteria and depends on the location of each individual criterion value between maximum and minimum values extracted from 24 observations for that criterion. For example, Operation Incidents values for ranking 1 and 24 are 9.36 and 5.27 respectively with maximum and minimum of 10.42 and 1.33 respectively. The same pattern can be observed for other KPIs such as Customer Incidents and Employee Incidents. The performance of each observation can be justified by comparing its outputs with maximum and minimum of each criterion.

The histogram of results is presented in Figure 3.

Comparing the Service and Manufacturing Sector Results

Service Sector

By considering Relative Closeness Index (Figure 2), it can be seen that in service sector the best performance among 24 sample companies belongs to Co. 7.1 and Co. 7.2 with 0.5206 and 0.44752 Relative

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Table 9. Rankings for manufacturing sector companies

No.	Sector	Company No.	S^+	S^-	Relative Closeness Index(Ci)	TOPSIS Ranking
1	Oil & Gas Producers (1)	Co. 1.1	10.4155	13.3947	0.56256	1
2		Co. 1.2	12.2712	12.1757	0.49805	8
3		Co. 1.3	12.6312	12.0605	0.48844	10
4	Aerospace & Defense (2)	Co. 2.1	11.2615	11.4162	0.50341	7
5		Co. 2.2	11.7927	11.0634	0.48405	13
6		Co. 2.3	12.7491	12.323	0.4915	9
7	Auto Components (3)	Co. 3.1	11.8167	12.3419	0.51087	6
8		Co. 3.2	10.984	12.4465	0.53121	4
9		Co. 3.3	11.0362	13.5173	0.55052	3
10	Transportation (4)	Co. 4.1	10.4952	12.9913	0.55314	2
11		Co. 4.2	12.6505	11.1683	0.46889	20
12		Co. 4.3	12.2134	11.4503	0.48388	14
13	Chemicals (5)	Co. 5.1	12.2365	11.6718	0.48819	11
14		Co. 5.2	12.4948	11.7242	0.48409	12
15		Co. 5.3	12.4875	10.8021	0.46382	21
16	Diversified Metals (6)	Co. 6.1	12.2415	10.9716	0.47265	19
17		Co. 6.2	12.6006	10.8338	0.4623	22
18		Co. 6.3	14.2684	8.8217	0.38206	24
19	Paper & Forestry (7)	Co. 7.1	12.5324	11.7212	0.48328	15
20		Co. 7.2	13.2031	11.2391	0.45982	23
21		Co. 7.3	12.7486	11.4983	0.47422	18
22	Precious Metals (8)	Co. 8.1	11.7775	12.8182	0.52116	5
23		Co. 8.2	13.6055	12.5904	0.48063	16
24		Co. 8.3	13.6699	12.3556	0.47475	17

Closeness (C_i) respectively both in Energy S. category. Energy S. category also shows the best performance among 8 different categories.

It is also considerable that among these 24 companies in service sector, most of them show the Relative Closeness (C_i) between 0.3 and 0.4 which is so far from the Ideal Solution; $C_i = 1$. It means based on maximum and minimum performance of each criterion in this sample, there is high potential for improvement.

This improvement opportunity comes from the fact that observations present almost the average of industry although most of them show maximum and minimum in some criteria.

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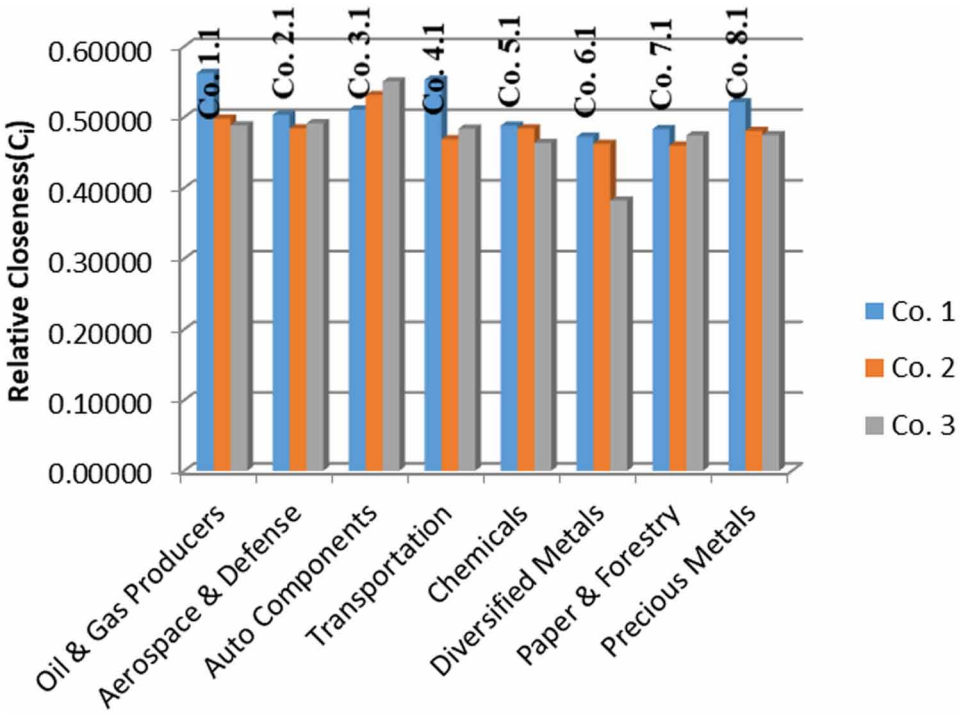
Figure 3. Relative closeness index (Ci) values for manufacturing sector companies



Manufacturing Sector

By considering Relative Closeness Index (Figure 3), it can be seen that in manufacturing sector the best performance among 24 sample companies belongs to Co. 1.1 in Oil & Gas producers and Co. 4.1 in Transportation Categories with 0.56256 and 0.55314 Relative Closeness (C_i) respectively. Nevertheless Auto Components category shows the best performance among 8 different categories with 3 companies with Relative Closeness (C_i) more than 0.5.

It is also considerable that among these 24 companies in manufacturing sector, most of them show the Relative Closeness (C_i) around 0.5 which is far from the Ideal Solution; $C_i = 1$. It means that based on maximum and minimum performance of each criterion in this sample, there is good potential for improvement.

However, it can be seen that between the two sectors; service and manufacturing, the performance of companies in manufacturing sector is obviously better than service sector with average Relative Closeness (C_i) 0.5 and 0.36 respectively. It means performance of companies in manufacturing sector is closer to the ideal solution of this sector compare to the same situation in service sector.

CONCLUSION AND FUTURE WORKS

In this research, the authors proposed a multicriteria framework for benchmarking sustainability performance of organizations using TOPSIS methodology. TOPSIS ranks the organizations based on relative

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closeness to ideal and non-ideal solutions. The indicators for sustainability measurement are developed using Sustainalytics database. The proposed techniques are applied on available data for Canadian companies. Two sectors (service and manufacturing) are considered. In each sector, eight categories and in each category three companies are evaluated making a total of 24 companies (or observations) in each sector. The results of this study show:

- Energy category giving the best performance among 8 different categories in service sector.
- Auto components category giving the best performance among 8 different categories in manufacturing sector with 3 companies having Relative Closeness (C_i) values more than 0.5.
- Among service and manufacturing, the manufacturing sector shows better performance with average Relative Closeness (C_i) values 0.5 and 0.36 respectively.

The current research has some limitations which can be translated into opportunities for further research as follows:

- In the proposed KPIs, financial dimension can be added.
- Other frameworks for example Global Reporting Initiative (GRI) and Dow Jones Sustainability Index (DJSI) can be considered to develop the model.
- As Sustainalytics database covers different regions, countries and industries, the context of country and multiple sectors could be further investigated.
- Combination of other MCDM techniques such as AHP with TOPSIS can be considered. Different types of fuzzy methods can also be investigated.
- Other types of efficiency definitions and various types of DEA method can also be added to study.

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Chapter 6
Assessing the Environmental Impacts of Green Collaboration in Land–Sea Freight Transport

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ABSTRACT

The purpose of this chapter is to study the benefits of collaboration among shippers in less than truckload transportation and to show the role of transhipments in the collaboration. In this chapter, the authors propose a new model for the pickup and delivery problem with transhipment and time windows to study the role of transhipment in the green collaborative transportation. A transportation network with two transportation modes road and sea is considered. Different scenarios are optimized and compared in terms of cost and CO_2 emissions: with/without collaboration and with/without transhipment. The proposed model is applied to a case study with real data from three agri-food companies in short sea shipping context. With this model, the total cost and the total amount of CO_2 emissions are reduced by using collaboration and transhipment. An experimental study was conducted to illustrate this positive impact.

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INTRODUCTION

Over the past decade, firms have adopted supply chain management as a critical element of their corporate strategies, but many firms do not realize the anticipated benefits of constructing collaborative operating relationships with supply chain partners. One of the directions in supply chain management is that of making the environment a main element of quality instead of considering it as a constraint (Morana, 2013) and defining green supply chain management policies and practices (Srivastava, 2007). Moreover, the term "collaboration" is currently one of the main terms associated with logistics and supply chain management, although it can take various interpretations and is mainly related to relations among supply chain partners at different echelons of the chain (Muckstadt et al., 2001). Despite the barriers that potentially deteriorate collaboration among companies for many industries all over the world, collaboration is becoming more of a necessity than an option. Different kinds of collaboration, namely vertical, horizontal and lateral (Simatupang and Sridharan, 2002), are implemented in several relationships, even in partnerships in supply chains.

Collaboration is about organizations and enterprises working together, and can be viewed as a concept going beyond normal commercial relationships. It is a departure from the anchor point of discreteness, which underlines spot market transactions to a relational exchange, as the roles of supplier and buyer are no longer narrowly defined terms of the simple transfer of ownership of products (Matopoulos et al., 2007). One of the major collaborating mechanisms in supply chains is the sharing of resources, which can take place at the level of warehousing, production and transportation. Concerning transportation, lack of collaboration (sharing, consolidation, transhipment) across the supply chain leads to empty running of vehicles (McKinnon, 2010). If supply chain partners are willing to collaborate, either with other actors in the same supply chain or with competitor companies, then higher levels of utilization will be achieved.

However, it is not possible to examine collaboration in distribution supply chains without exploring in-depth the changes that occur at the transport system level. Indeed, the different forms of collaboration in logistics impact the form and organization of the transport systems used to distribute freight, as well as the different logistics platforms (Gonzalez-Feliu and Morana, 2011). According to Gonzalez-Feliu et al. (2013), collaboration can be carried out vertically (i.e., among complementary stakeholders at different echelons of the supply chain) or horizontally (i.e., among stakeholders of the same echelon in supply chains, sometimes under competition). D'Amours and Ronnqvist (2010) state the opportunities that collaborative planning can give to the different supply chain stakeholders and discuss the main issues in information and decisions technologies.

In this paper, the authors propose a scenario assessment to examine the suitability of collaboration among shippers at the distribution level. To do this, the authors propose a linear model derived from the operations research literature (Berbeglia et al., 2007; Parragh et al., 2007) to study the role of transhipment in green collaborative transportation. A transportation network with two transportation modes—road and sea—is considered. Different scenarios will be optimized and compared regarding cost and CO_2 emissions: with/without collaboration and with/without transhipment. To the best of the authors' knowledge, these transportation network scenarios have not been addressed until now. After the introduction, the second section will be devoted to review existing works in the literature dealing with sharing trucks for distribution in supply chain networks, collaborative transportation management and the modelling and solving processes for transportation problems with transhipments and pick-ups and deliveries. In the third section, the authors address the problem studied and present the mathematical model. Finally, in the fourth section, this study is illustrated by a case study in a short-sea-shipping context.

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LITERATURE REVIEW

To make the link between transhipment and collaborative transportation in the proposed model, let us first introduce existing works in the literature dealing with the concept of collaboration in transportation and then review works focusing on transhipment in vehicle routing problems.

Collaborative Transportation

The increasing fuel prices and the fierce market competition create more urgency for transportation providers to improve their transportation planning. Collaboration is an effective way for them to achieve this goal, which gives rise to the topic of collaborative, or cooperative, transportation (Lindholm and Browne, 2013). Such a collaboration can be facilitated by enablers. After identifying several enablers in the literature, Grzybowska et al. (2014) conducted a survey to identify the relationships among the various enablers. Most papers in the literature are based on vehicle routing problems (VRP) and propose models for the operational level of the supply chain. Kopfer and Krajewska (2007) present an overview and a comparison of existing approaches for an integrated transportation and forwarding problem. There are several types of horizontal collaboration in terms of transport (Liu et al., 2010). The first is that of transportation pooling among shippers. Indeed, two or more shippers can collaborate to minimize their costs. In fact, shippers are exposed to shorter and shorter customers' lead-time and have to send more often lower quantities of product. In this context of transportation less than a truckload, they can collaborate with other shippers to propose common shipments to a carrier to minimize their transportation costs. Shippers that provide a full truckload can also collaborate to minimize empty backhauling to the carrier.

There are few works on shippers' collaboration problems. Ergun et al. (2007a and 2007b) formulate this shipper collaboration problem as a lane-covering problem (LCP), which is covering a subset of arcs in a directed Euclidean graph by creating constrained cycles of a minimum cost. They also present and study a variant of the LCP, the cardinality-constrained lane-covering problem, in which the number of arcs in each cycle is lower than a predefined number and another version of the LCP to solve the shipper collaboration problem: the time-constrained lane-covering problem. Yilmaz and Savasaneril (2012) propose a model for the less-than-truckload shipper collaboration problem. After describing the behaviour of the shippers in the collaboration, they propose two methods for allocating cost-benefits. In Pan et al. (2013), the flows between two stages of supply chain are pooled. Before pooling, flows from suppliers go directly to the distribution centre. After pooling, upstream or downstream hubs can be located. Flows can go from upstream hubs to downstream hubs, from upstream hubs to the distribution centre or from suppliers to downstream hubs. Some direct flows can be conserved. They formulate a model for this problem considering greenhouse gas emissions and two modes of transportation—rail and road. Their goal is to minimize the total gas emissions of the network and they solve the problem with CPLEX. Danloup et al. (2015) propose a model for shippers' collaboration with soft time windows. They allow vehicles to deliver late, but they include a penalty fee linear to the number of hours the vehicle is late.

Another problem in collaborative transportation is the carriers' collaboration problem. Carriers' collaboration considers how carriers can reduce costs by sharing their vehicle capacities and transportation tasks, given the tasks that they have to serve. In less-than-truckload (LTL) transportation, collaboration can optimize the load of the trucks. In full truckload (FTL) transportation, collaboration can minimize backhauling.

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In Audy et al. (2007), a framework is proposed to describe collaboration in transportation of eight forest companies. They describe strategic, tactical, operational and real-time transportation planning decisions and raise issues about implementing collaborative decision processes. Liu et al. (2010) propose a model for a carrier collaboration system called the multi-depot capacitated arc routing problem with full truckloads. Hernández et al. (2011) propose a model for a small- to medium-sized less-than-truckload carrier collaboration problem under dynamic capacities. They first describe the formulation of their dynamic carrier collaboration model in which a set of collaborative routes that minimize the total cost is identified. They also compare the collaboration with the short-term leasing and show that collaboration is always beneficial. Dai and Chen (2012) propose a method based on Lagrangian Relaxation to solve the collaborative transportation planning problem with multiple carriers in less-than-truckload transportation. Wang and Kopfer (2014) propose a request exchange mechanism between carriers. They test their method with newly generated instances and show that their mechanism gives better results than transport planning without collaboration. liu et al. (2016) propose a Pickup and Delivery Problem (PDP) to solve the carriers' collaboration problem. Each carrier has a pool of requests that have to be handled by itself, and a pool of requests that can be handled by any carrier. A profit is associated with each request and the goal is to maximize the profit. They propose a formulation and a Large Neighbourhood Search (LNS) for this problem.

Pickup and Delivery Problem With Transhipment and Time Windows (PDPTTW)

Most of the papers dealing with collaborative transportation are based on or can be related to routing problems and especially to the PDP. This problem has been well studied and surveys can be found in Berbeglia et al. (2007) and in Parragh et al. (2008). In this paper, the authors focus on a variant of the PDP, the Pickup and Delivery Problem with Transhipments. In this problem, requests can be handled by several vehicles.

Opposing the classic pickup and delivery problem with time windows (PDPTW), only few papers in the literature deal with the PDPTTW. Several authors address the mixed integer linear programming (MIP) model for the PDPTTW and the exact method to solve it. Cortés et al. (2010) propose a mathematical formulation of the PDPTTW. In this problem, specific transhipment nodes are added where requests can be transferred between different vehicles before reaching the delivery point. They do not allow the requests to be split. They also develop a branch-and-cut algorithm to solve the problem and are able to solve instances with six requests. Rais et al. (2014) propose a new model for the PDPTTW considering several variants. They consider with and without time windows, heterogeneous fleets of vehicles, variable size fleets, split or not requests and a limited number of transfer nodes visited by a vehicle. They use GUROBI optimization software to solve the PDPTTW with time windows, heterogeneous fleets and not split requests, and are able to solve instances with seven requests.

Due to the complexity of the problem, several papers focus on heuristic or meta-heuristics methods to solve it. Shang and Cuff (1996) first propose a heuristic to solve the PDPTTW. They develop a heuristic for a multi-objective vehicle routing and scheduling problem where they minimize the costs, tardiness and travel time. They create mini-routes based on requests and then use an insertion heuristic to insert them into the vehicle routes. They apply their heuristic on data provided by a health maintenance organization. Their network is composed of nine pickup and delivery locations. Thangiah et al. (2007) also propose an insertion-based heuristic to solve the PDPTTW. They extend it by adding a local search to improve the initial solutions. They use two main local search operators to improve a solution. According

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to the authors, the local search operators greatly improve the solutions. Qu and Bard (2012) propose a two-phase heuristic. In the first phase, they use a GRASP heuristic to generate an initial solution. In the second phase, they use an adaptive large neighbourhood search algorithm. They solve instances with 25 requests. Masson et al. (2013) propose an adaptive large neighbourhood search to solve the PDPTTW and apply their method to real instances of scholar transportation of disabled children. They solve networks with up to 200 pickup and delivery locations. Danloup et al. (2018) propose an LNS and a genetic algorithm. They improve the solutions of the instances from Qu and Bard (2012).

Other Routing Problems With Transhipments

Transhipments are also allowed in other routing problems like vehicle routing problems with transhipments (Drexl, 2013), crossdocking problems (Wen et al., 2009; Gonzalez-Feliu, 2013) and multi-echelon routing problems (Gonzalez-Feliu, 2012; Cuda et al., 2015). Vehicle routing problems with crossdocking (Wen et al., 2009) are defined as two-stage transport systems with a first stage consisting of pickup routes that feed one or more crossdocking points. From those points, a second stage of delivery routes is defined. Lee et al. (2006) propose a mathematical formulation and a tabu search for the VRP with crossdocking. Wen et al. (2009) propose a tabu search heuristic embedded within an adaptive memory procedure and apply it to real-based data. A variant of this problem can be defined for PDP problems (also called many-to-many PDP; Berbeglia et al., 2007). Santos et al. (2011) propose a set partitioning formulation and a branch-and-prize algorithm. Petersen and Ropke (2011) propose an LNS to solve the PDP with crossdocking and solve instances with up to 200 nodes.

The VRP with transhipments differs from the VRP with crossdocking in the fact that all routes are delivery ones. When observing in detail this problem, it is similar to the multi-echelon VRP or the multi-echelon LRP. In all those problems, a multi-stage system is defined (Gonzalez-Feliu, 2012). In those problems three types of nodes are defined: (1) *depots*, i.e., the starting points of the distribution, (2) *e-satellites*, i.e., intermediary facilities associated to each stage *e*, where freight is transhipped, and (3) *customers*, defined as the final destinations of the freight.

The literature on two-echelon VRP and two-echelon LRP is wide, and several methods are proposed, the exact methods of Baldacci et al. (2013) and Contardo et al. (2012) being the most performant for the 2E-VRP (solving to optimality instances up to 50 customers) and the 2E-LRP (solving instances up to 200 customers), respectively. Hemmelmayr et al. (2012) have proposed the best performing heuristic, an adaptive large neighbourhood search algorithm. Those problems can be generalized to n-echelons. Gonzalez-Feliu (2012, 2013) presents the main concepts and standards of multi-echelon–based vehicle routing optimization problems. He presents a model and a classification of solving methods for these problems, considering 2E-VRP, 2E-LPR and truck-and-trailer routing problems (TTRP) as sub-problems of the same family, as stated in Nagy and Salhi (2007). Cuda et al. (2015) propose a recent literature review on 2E-VRP. What is stated in those review works is that most problems deal with multi-stage transportation systems where the synchronization is not included in the optimization, the condition linking the echelons being only of precedence (i.e., echelon i-1 routes need to be done before echelon i routes but no coordination and synchronization is included explicitly in the optimization problems).

Lastly, some works deal with those synchronization constraints. Crainic et al. (2009) include time synchronization on a systemic model for multi-echelon city logistics optimization in a theoretical analysis. Drexl (2013) proposes a model for the VRP with transhipments. He shows that VRP with multiple

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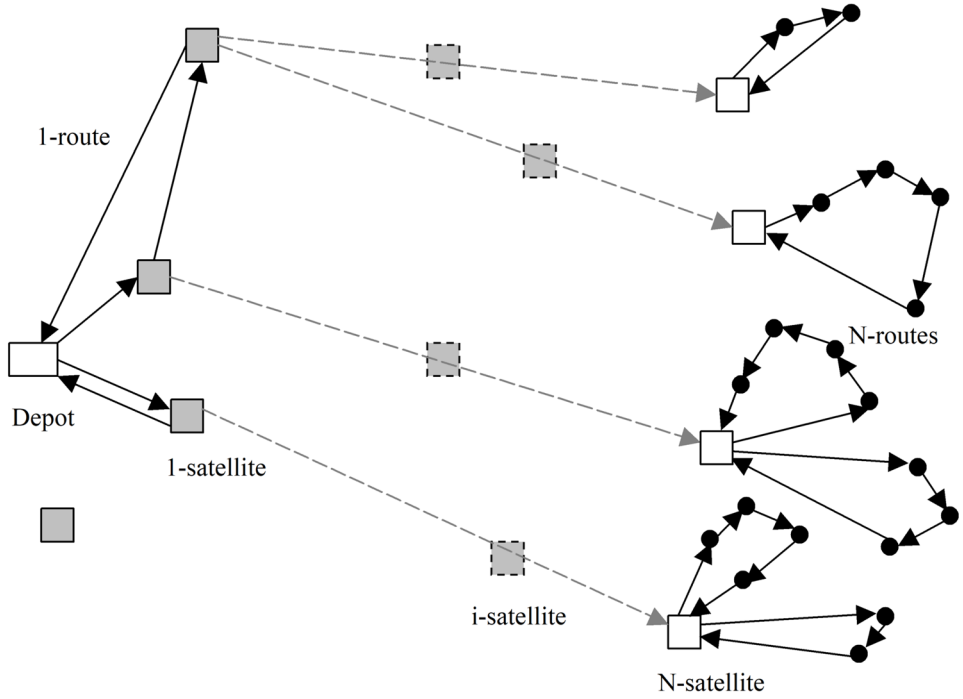
Figure 1. Example of an N-stage distribution network (Gonzalez-Feliu, 2012)



synchronization constraints such as multi-level VRP and simultaneous vehicle and crew routing problems can be modelled as a VRP with transhipments.

Even transhipment could be a facilitator for collaborative routing. Vornhusen et al. (2014) propose an MIP formulation for the PDPTTW and use it in the context of carriers' collaboration. They apply their model on generated data and show that transhipment can help to reduce total transportation costs of a coalition of carriers. That is why this paper proposes to deal with collaborative routing using transhipment to optimize cost and minimize CO_2 emissions. Moreover, the proposed solution approach is illustrated by a real case study. The proposed work has on one hand an added value regarding what already exists in the literature since the authors deal at the same time with collaboration and transhipment. On the other hand the propose work has a positive impact on managerial issues since an aided decision-making approach is provided to optimize at the same time cost and CO_2 emissions.

As shown in this overview of the literature, the issue of horizontal collaboration among shippers is only partially explored and, when relating it to transport, existing works deal mainly with finding optima. However, another use of operations research and optimization can be that of making scenario assessments, if related to the reality the models and methods aim to represent (Ackoff, 1977). This work aims to propose an approach to assess the suitability of improving environmental performance of distribution-based supply chains by horizontal collaboration among shippers, by using those optimization methods to find suitable configuration of the distribution schemes.

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The Inclusion of Environmental Impacts in Freight Transport Planning

Traditionally, the criteria and goals considered in freight transport planning and management have been mainly economic (costs, distances and travel times; Crainic and Laporte, 1997). However, in recent years, the consideration of environmental impacts as a decision variable in freight transport planning has increased. In order to include environmental impact in the costs calculation, this impact has to be expressed in external costs. Several reports made for the European Commission (Maibach et al., 2008; Martino et al., 2009; Korzhenevych et al., 2014) review and summarize works on how to calculate such costs. Using these, impacts such as air pollution, climate change, noise or congestion, for example, can be related to economical costs and added in an objective function or in constraints. For example, Guyon et al. (2012) define a location problem for last-mile delivery system design that includes economic, environmental and social costs. Ponderation factors are applied to each cost in order to give priority to one or another sphere of sustainable development. That approach has already been used in distribution logistics (Harris et al., 2009). A similar reasoning is followed in Crainic et al. (2012), who define a two-echelon vehicle routing problem using a generalized cost function that includes the same three spheres (economic, environmental and social) with ponderation weights. Staniek and Sierpinski (2016) propose a platform to optimize supply chains, multimodal transport and routing by minimizing emissions, noise and congestion.

Another set of problems is related to green vehicle routing (Erdoğan and Miller-Hooks, 2012). The problems are similar to classical VRP variants but concern more environmentally friendly vehicles. In this family of problems, the environmental aspects are represented by environmentally friendly vehicles and not by an aim of minimizing environmental impacts (Lin et al., 2014). Other combinatorial optimization approaches can be applied to green logistics planning and management (Sbihi and Eglese, 2007), although, in general, the consideration of economic and environmental aspects and the choice among them are seldom included in optimization (except for the problems proposed above). Most papers use classical optimization algorithms to assess scenarios then compare them using multi-criteria decision support, the optimization algorithm being related to only distance or cost minimization. Then the results are used to estimate the different criteria (costs, environmental impacts etc.) for each scenario to feed the multi-criteria method (Macharis et al., 2010; Awasthi and Chauhan, 2011).

METHODOLOGY

The main contribution of the paper is to propose a scenario assessment of horizontal collaboration strategies among shippers to examine the impacts of that collaboration on both the transportations system organization and the environment. Moreover, to assess those scenarios, a combinatorial optimization approach is developed to take into account different considerations concerning the importance of economic and environmental elements. Moreover, the consideration of those two elements will be done in a homogeneous way, i.e., producing economic and environmental impacts in a homogeneous way in order to allow the combination of both in a unique objective function.

The methodology is articulated as follows: first, the transportation system that aims to be assessed is characterized. That means examining the different transportation schemes related to the multimodal freight distribution system, with and without collaboration. After defining the transport system and its variants, a combinatorial optimization problem is proposed. In that proposal, the transportation system

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is translated into a linear optimization problem, considering as objective function both economic and environmental impacts, as well as ponderation coefficients in order to prioritize economic or environmental impacts, or give the same importance to each of them.

With the obtained linear programming model, different scenarios can be assessed. The third part of the methodology is the definition of the scenarios as well as their characterization. Finally, and using the obtained model, those scenarios can be assessed, compared and analysed.

The first two parts (definition of the transportation problem and formulation of the linear programming model) are presented below. The two last parts (scenario definition and assessment) are presented in the following section via an illustration example.

Notations

Parameters

O - Set of suppliers
D - Set of customers
USH - Set of upstream hubs
DSH - Set of downstream hubs
V - Set of vehicles
K - Set of commodities
E_{start} - Emissions for starting the engine ($kgCO_2/km$)
E_{hot} - Emissions for a running engine ($kgCO_2/km$)
$E_{evaporation}$ - Evaporation emissions of the fuel ($kgCO_2/km$)
$E_{average}$ - Average emissions of a vehicle per km ($kgCO_2/km$)
E_{full} - Emissions of a full-load vehicle ($kgCO_2/km$)
E^{v}_{empty} - Emissions of an empty vehicle of type v ($kgCO_2/km$)
E^{v}_{pallet} - Emissions per pallet added in a vehicle v ($kgCO_2/km$)
C^{v}_{km} - Cost per vehicle per km (€) (fuel consumption, maintenance…)
C^{v}_{hour} - Cost per vehicle per hour (€) (cost of drivers…)
C^{v}_{fixed} - Fixed cost per vehicle (€)
Q^{v} - Capacity of vehicle v (pallet)
M - A very large constant
d_{ij} - Distance between i and j (km)
t_{ij} - Travel time from site i to site j (h)
q^{k}_{ij} - Quantity of product k to deliver from site i to site j (pallet)
A^{min}_{i} - Minimum arrival time at site i
A^{max}_{i} - Maximum arrival time at site i
u^{v}_{i} - Service time of vehicle v at site i
α – Weight of the CO_2 emissions in the objective function
β – Weight of the costs in the objective function

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Decision variables

x_{ij}^{v} - 1 if vehicle v travels between nodes i and j
y_{ij}^{vk} - Quantity of product k in vehicle v between nodes i and j
a_{i}^{v} - Start of service time of vehicle v at site i
b_{i}^{v} - End of service time of vehicle v at site i
w_{i}^{v} - Waiting time of vehicle v at site i
$z_{ik}^{vv'}$ - Quantity of product k transferred from v to v' at node i
u_{ik}^{v} - 1 if vehicle v picks up some product k at transhipment node i
$r_{i}^{vv'}$ - 1 if there is a transhipment from vehicle v to vehicle v' at node i

Definition of the Transportation Problem

This considered transportation network is a short-sea-shipping network derived from a case study about collaborative transportation between three agri-food companies (named here as A, B and C) that are transformers. These companies are all based in the UK and have customers across northwest continental Europe. Thus, products have to cross the sea between the suppliers in the UK and the customers in continental Europe. Four ports in the UK play the role of upstream hubs and four ports in continental Europe play the role of downstream hubs. The three suppliers have a total of 72 customers dispatched in France, Belgium, Germany, Netherlands and Denmark. In the actual or "as is" case, they sent their products separately to each of their customers (Figure 2). The solid lines represent the trucks sent by supplier A, the dashed lines represent the trucks sent by supplier B and the dashed-dotted lines represent the trucks sent by supplier C. All the connections between the UK ports and the European ports are not allowed. For simplification, all the ports and customers are not represented in the figures.

The goal of this case study is to compare several scenarios of collaboration in term of costs and CO_2 emissions. In scenario 1 ("as is" case), the three suppliers perform their routing independently from each other. In scenario 2 (Figure 3), the three suppliers collaborate to perform their routing at the same time. In scenario 3 (Figure 4), the three suppliers still collaborate to perform common routing. But, contrary to the previous scenarios, the ports are used as transhipments points in scenario 3, which means shipments can be transferred from one vehicle to another, but only in the ports. In Figures 2, 3 and 4, the solid lines, dashed lines and dashed-dotted lines represent three different vehicles. To summarize, scenarios 0 and 1 are scenarios without collaboration between the suppliers; scenarios 2 and 3 are scenarios with collaboration between the suppliers; and scenario 3 is the only scenario where transhipments are possible at the ports.

In terms of transport planning, the overall system is a three-stage transport system with transhipments. Four types of facilities are therefore defined: suppliers in the UK (the agri-food producers), UK ports, European ports and customers located in continental Europe. In all scenarios, the sea transport flows are Full Truckload (FTL) trips between UK ports and European ports. However, since the choice of departure and arrival ports is a decision for transport planning and needs then to be modelled, this stage needs to be considered explicitly. For scenario 1, since there is no collaboration, the first stage of transport is a group of FTL trips between each supplier and a port, and delivery routes from a European port to customers are LTL transport chains (routes) exclusive to each supplier. For scenario 2, flows be-

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tween suppliers and UK ports make it possible to deploy pickup routes where the freight from different suppliers can be jointly loaded into the same truck to feed the ports. However, at destination, distribution routes remain exclusive to each supplier (i.e., each route contains the freight of only one supplier). For scenario 3, the first stage of transport (flows between suppliers and UK ports) remain the same as for scenario 2, but distribution flows between a European port and the customers will contain freight from different suppliers to propose a better optimized set of routes and consequently reduce overall distribution costs. To do this, it is important to make transhipments and consolidation at a European port in order to make joint distribution routes to deliver customers. An example of those three transport systems are presented in Figures 2 to 4:

Figure 2. Distribution network without collaboration (scenario 1)

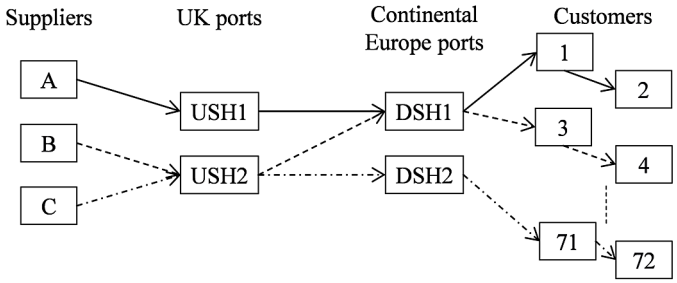


Figure 3. Distribution network with collaboration (scenario 2)

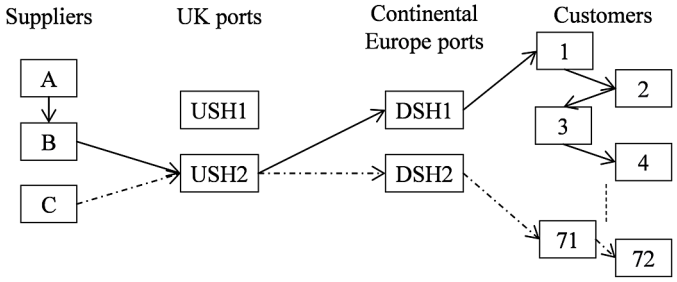
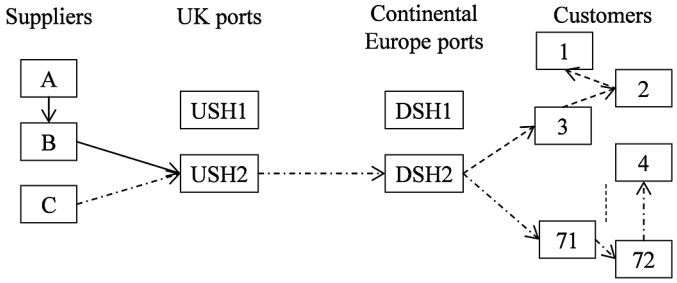


Figure 4. Distribution network with collaboration and with transhipments (scenario 3)



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The problem studied is formulated as a collaborative routing problem with two-stage transhipment. Involved partners in the collaboration are shippers and/or recipients. The purpose of collaboration partners is to group their shipments in order to propose full truckloads shipment to carriers. This problem can be defined on a graph

$$G = \{O \cup USH \cup DSH \cup D, A\}$$

where the set of nodes is the union of four sets: the set of suppliers or origin nodes (O), the set of upstream hubs (USH), the set of downstream hubs (DSH) and the set of customers or destination nodes (D). A node can appear only in one set. As the authors focus on shippers and recipients' collaboration, the authors do not consider carriers' depot. The set of arcs A is composed of five subsets: those between the suppliers, those from the suppliers to the upstream hubs, those from the upstream hubs to the downstream hubs, those from the downstream hubs to the customers and those between the customers. In this problem, a fixed heterogeneous fleet of vehicles with limited capacity is considered. Also, the possibility of supplying several commodities is considered and one commodity can be supply by several suppliers. Each request is represented by a supplier-customer pair, a commodity and a volume. There is only one request per pair per commodity. All requests can be split, i.e., a request can be served by several vehicles. Finally, the authors consider time windows (TW). A vehicle must be served in a time slot predefined for each node. If it arrives before, it can wait, but it cannot arrive after. The service time at a node is fixed for each node.

In the proposed distribution system, either FTL or LTL transport flows are made by transport carriers that execute transport, and prices are asked only for loaded transport (unloaded vehicles are included in the costs of carriers, but prices paid by shippers are related to only loaded vehicles). For this reason, and from the viewpoint of shippers, empty vehicle transport is not considered in the optimization. Consequently, and as there is no depot defined for routes, each vehicle can start and finish its route at any node. The flow constraints are on the shipments. Each shipment has to start from its origin point. Then the vehicle can visit several other suppliers to pick up goods. It has to go through one upstream hub and then one downstream hub. Finally, it can visit several customers before arriving at its destination. Upstream and downstream hubs are transhipment points, so a shipment can be transferred from a vehicle to another only in these hubs. For simplification and also because the authors focus on transportation only, the authors do not consider any additional transhipment costs inside the hubs. The difference between an upstream hub and a downstream hub is that an upstream hub is located near the suppliers and the downstream hub is located near the customers. The direct delivery from a supplier to a customer is not allowed.

Estimation of the Environmental Impacts and Economic Costs

In this paper, the authors aim to examine different optimization viewpoints regarding the importance of economic and environmental impacts. To do this, the authors include in the objective function of model both economic costs and CO_2 emissions. The exact calculation of emissions is a complex work because of the quantity of parameters to consider such as speed, engine consumption, driver's behaviour, weather, etc. Moreover, and following Ackoff's (1977) principles, it is important to examine the reality that the model aims to represent. The aim is to add both economic and environmental impacts, in a homogeneous way, in order to compare scenarios. Since scenarios are assessed using the same frameworks, eventual errors

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of bias are reproduced homogeneously in all scenarios, making the differences between two scenarios homogeneous and comparable (Gonzalez-Feliu, 2017). In that context, a simplified estimation is suitable. The estimation method has been defined according to a synthesis of different works and approaches (Hickman et al., 1999; Jancovici, 2007; Ubeda et al., 2011; Rexeis et al., 2013). The CO_2 emissions of a freight distribution system can be estimated using equation (1), where $E_{truck\text{-}inbound}$ are the unitary emissions (per unity of weight and distance) for the inbound flows (from shippers' location to port), E_{sea} those for sea transport and $E_{truck\text{-}outbound}$ those for outbound transport (from port to final destinations).

For each transport mode, those emissions E_m follow the relation (2). For simplification, the authors consider only hot emissions here as the other emissions can be neglected according to the distance travelled. To calculate the hot emissions, the authors use equations (3) to (5) (Jancovici, 2007), where *Tdv* is the empty transport rate, *Trm* is the full transport rate and 0.44 corresponds to the overconsumption between full and empty vehicle. Finally, to calculate the average emissions the authors use equation (7).

The transportation costs are also calculated. According to the French National Road Committee (CNR), the transportation cost depends on three values: the cost per kilometre C_{KM}, mainly related to the fuel consumption, but also to maintenance costs which are in general a function of the distance; the cost per hour C_{How}, i.e., a variable cost related to time which includes the driven and stop time (to include not only the drivers' time, but also the loading and unloading operations, among others) and is mainly related to drivers' salaries; and a fixed cost per vehicle C_{Fixed}, related not only to the acquisition or rental of the vehicle but also to other fixed costs of the transportation carrier, like facilities, land employees, current expenses like electricity or internet and commercial costs, among others. Therefore, the transportation cost is the sum of these three terms of equation (8).

$$E = E_{truck-inbound} + E_{sea} + E_{truck-outbound} \tag{1}$$

$$E_m = E_{start} + E_{hot} + E_{evaporation} \tag{2}$$

$$E_{hot} = \mathrm{d}^*\left(E_{empty} + \mathrm{y}^*E_{pallet}\right) \tag{3}$$

$$E_{pallet} = \frac{E_{full} - E_{empty}}{Q} \tag{4}$$

$$E_{empty} = \frac{E_{average}}{\left(1 + 0.44^*\left(1 - Tdv\right)^* Trm\right)} \tag{5}$$

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$$E_{full} = E_{empty} * 1.44 \tag{6}$$

$$E_{average} = Fc * Fcf \tag{7}$$

$$d * C_{km} + t * C_{hour} + C_{fixed} \tag{8}$$

The Linear Programming Model

The objective function (9) of the model is to minimize both total CO_2 emissions and total costs. This objective function is composed of two major terms. The first major term corresponds to the emissions and it is composed of two minor terms; the first minor term corresponds to the emissions of all vehicles without considering their loads, and the second minor term is the additional emissions due to the loads of vehicles. The second major term corresponds to the costs and it is composed of three minor terms; the first minor term corresponds to the cost per kilometre, the second minor term corresponds to the cost per hour and the third minor term corresponds to the fixed cost. Both emissions and costs have a weight (α and β) comprised between 0 and 1 so the authors can give more importance to the emissions or to the costs.

$$\text{Min}\,\alpha\left(\sum_{i\in O\cup D}\sum_{j\in O\cup D}\sum_{v\in V}\left(E^{v}_{empty}d_{ij}x^{v}_{ij}+\sum_{k\in K}E^{v}_{pallet}d_{ij}y^{vk}_{ij}\right)\right)+\beta\left(\sum_{i\in O\cup D}\sum_{j\in O\cup D}\sum_{v\in V}\left(C^{v}_{km}d_{ij}x^{v}_{ij}+C^{v}_{hour}t_{ij}x^{v}_{ij}\right)+\sum_{v\in V}C^{v}_{fixed}\right) \tag{9}$$

The constraints of the problem are:

$$\sum_{v\in V}\left(\sum_{j\in O}y^{vk}_{ij}+\sum_{j\in USH}y^{vk}_{ij}-\sum_{j\in O}y^{vk}_{ji}\right)=\sum_{j\in D}q^{k}_{ij},\ \forall i\in O,\forall k\in K \tag{10}$$

$$\sum_{v\in V}\left(\sum_{i\in DSH}y^{vk}_{ij}+\sum_{i\in D}y^{vk}_{ij}-\sum_{i\in D}y^{vk}_{ji}\right)=\sum_{i\in O}q^{k}_{ij},\ \forall j\in D,\forall k\in K \tag{11}$$

The constraint (10) ensures that the quantity of product that a supplier must supply is respected. In the same way, the constraint (11) ensures that the demand of a customer for a product is respected. In the constraint (10), the first and second terms correspond to the quantity of products *k* leaving the supplier *i* and the third term corresponds to the quantity of products *k* entering the supplier *i*. In the constraint (11), the first and second terms correspond to the quantity of products *k* entering the customer *j* and the third term corresponds to the quantity of products *k* leaving the customer *j*.

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$$\sum_{j\in O} y_{ij}^{vk} + \sum_{j\in USH} y_{ij}^{vk} \geq \sum_{j\in O} y_{ji}^{vk}, \forall i \in O, \forall v \in V, \forall k \in K \tag{12}$$

$$\sum_{i\in DSH} y_{ij}^{vk} + \sum_{i\in D} y_{ij}^{vk} \geq \sum_{i\in D} y_{ji}^{vk}, \forall j \in D, \forall v \in V, \forall k \in K \tag{13}$$

Constraints (12) and (13) respect the fact that a vehicle must be loaded at a supplier and unloaded at a customer. Indeed, when leaving a supplier, the quantity of products in the truck must be more or equal to that before it arrives, corresponding to the quantity loaded (12). On the other side, when leaving a customer, the quantity of product must be less or equal to that before it arrives, corresponding to the quantity unloaded (13).

$$\sum_{j\in O}\sum_{v\in V} y_{ji}^{vk} = \sum_{j\in DSH}\sum_{v\in V} y_{ij}^{vk}, \forall i \in USH, \forall k \in K \tag{14}$$

$$\sum_{j\in USH}\sum_{v\in V} y_{ji}^{vk} = \sum_{j\in D}\sum_{v\in V} y_{ij}^{vk}, \forall i \in DSH, \forall k \in K \tag{15}$$

The constraints (14) and (15) ensure that the quantity of products leaving a hub is equal to the quantity of products entering the hub. These constraints allow also the consolidation in the hubs.

$$\sum_{j\in O} x_{ij}^{v} + \sum_{j\in USH} x_{ij}^{v} \leq 1, \forall i \in O, \forall v \in V \tag{16}$$

$$\sum_{j\in D} x_{ij}^{v} \leq 1, \forall i \in D, \forall v \in V \tag{17}$$

$$\sum_{j\in O} x_{ji}^{v} \leq 1, \forall i \in O, \forall v \in V \tag{18}$$

$$\sum_{i\in DSH} x_{ij}^{v} + \sum_{i\in D} x_{ij}^{v} \leq 1, \forall j \in D, \forall v \in V \tag{19}$$

$$\sum_{o\in O}\sum_{m\in USH} x_{om}^{v} \leq 1, \forall v \in V \tag{20}$$

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$$\sum_{m\in USH}\sum_{n\in DSH} x^{v}_{mn} \leq 1, \forall v \in V \tag{21}$$

$$\sum_{n\in DSH}\sum_{d\in D} x^{v}_{nd} \leq 1, \forall v \in V \tag{22}$$

Constraints (16) to (22) ensure that a vehicle passes through each node once, maximum. Constraints (16) and (17) ensure that a vehicle goes to only one another node, maximum, when leaving a supplier or a customer, respectively. In the same way, constraints (18) and respectively (19) ensure that a vehicle comes from only one direction maximum when arriving at a supplier and a customer, respectively. Constraints (20), (21) and (22) ensure that a vehicle passes through one upstream hub and one downstream hub, maximum.

$$Q^{v}x^{v}_{ij} \geq \sum_{k\in K} y^{vk}_{ij}, \forall i,j \in O \cup D, \forall v \in V \tag{23}$$

Constraints (23) are the vehicles capacity constraints.

$$b^{v}_{i} + t_{ij} + w^{v}_{j} - a^{v}_{j} \leq M\left(1 - x^{v}_{ij}\right), \forall i,j \in O \cup USH \cup DSH \cup D, \forall v \in V \tag{24}$$

$$b^{v}_{i} + \mathrm{t}_{ij} + w^{v}_{j} - a^{v}_{j} \geq -M\left(1 - x^{v}_{ij}\right), \forall i,j \in O \cup USH \cup DSH \cup D, \forall v \in V \tag{25}$$

$$a^{v}_{i} + u^{v}_{i} = b^{v}_{i}, \forall i \in O, \forall v \in V \tag{26}$$

$$a^{v}_{j} + u^{v}_{j} = b^{v}_{j}, \forall j \in D, \forall v \in V \tag{27}$$

$$a^{v}_{i} \geq A^{min}_{i}, \forall i \in O \cup USH \cup DSH \cup D, \forall v \in V \tag{28}$$

$$a^{v}_{i} \leq A^{max}_{i}, \forall i \in O \cup USH \cup DSH \cup D, \forall v \in V \tag{29}$$

Constraints (24) to (29) are the constraints relative to the time windows. Constraints (24) to (27) ensure the respect of the travel time and the loading/unloading time. Constraints (24) and (25) ensure that, if a vehicle uses arc *ij*, the start of service time at *j* of the vehicle is equal to its end of service time at *i* plus

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the travel time between *i* and *j* plus the waiting time at *j*. Constraints (26) and (27) ensure that the end of service time of a vehicle at *i* is equal to its start of service time plus the service time at *i*. Constraints (28) and (29) ensure that the time windows are respected.

$$\sum_{i\in O} y_{ij}^{vk} - \sum_{i\in DSH} y_{ji}^{vk} \leq \sum_{v'\in V, v'\neq v} z_{jk}^{vv'}, \forall j \in USH, \forall v \in V,\ \forall k \in K \tag{30}$$

$$\sum_{i\in USH} y_{ij}^{vk} - \sum_{i\in D} y_{ji}^{vk} \leq \sum_{v'\in V, v'\neq v} z_{jk}^{vv'},\ \forall j \in DSH, \forall v \in V,\ \forall k \in K \tag{31}$$

$$z_{jk}^{vv'} + \sum_{i\in DSH} y_{ji}^{vk} - \sum_{i\in O} y_{ij}^{vk} \leq M\left(1 - u_{jk}^{v'}\right),\quad \forall j \in USH, \forall v, v' \in V, v \neq v',\ \forall k \in K \tag{32}$$

$$z_{jk}^{vv'} + \sum_{i\in D} y_{ji}^{vk} - \sum_{i\in USH} y_{ij}^{vk} \leq M\left(1 - u_{jk}^{v'}\right),\quad \forall j \in DSH, \forall v, v' \in \mathrm{V}, v \neq v',\ \forall k \in K \tag{33}$$

$$z_{ik}^{vv'} \leq M u_{ik}^{v'}, \forall i \in USH \cup DSH, \forall v, v' \in V, v \neq v',\ \forall k \in K \tag{34}$$

$$\sum_{i\in DSH} y_{ji}^{vk} - \sum_{i\in O} y_{ij}^{vk} \leq M u_{jk}^{v'k}, \forall j \in USH, \forall v, v' \in V, v \neq v',\ \forall k \in K \tag{35}$$

$$\sum_{i\in D} \mathrm{y}_{ji}^{vk} - \sum_{i\in USH} y_{ij}^{vk} \leq M u_{jk}^{v'k}, \forall j \in DSH, \forall v, v' \in V, v \neq v',\ \forall k \in K \tag{36}$$

$$z_{ik}^{vv'} \leq M r_{i}^{vv'}, \forall i \in USH \cup DSH, \forall v, v' \in V, v \neq v',\ \forall k \in K \tag{37}$$

$$a_{i}^{v} - b_{i}^{v'} \leq M r_{i}^{vv'}, \forall i \in US\mathrm{H} \cup \mathrm{D}SH, \forall v, v' \in V, v \neq v' \tag{38}$$

The constraints (30) to (38) are the constraints relative to the synchronization at the transhipment points. The constraints (30) to (36) calculate the quantity of products transferred from one vehicle to another in a hub. Constraints (30) and (31) calculate the minimum quantity of products that a vehicle must drop in an upstream hub and in a downstream hub. Constraints (32) and (33) calculate the maximum quantity of

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products that can be transferred from a vehicle *v* to a vehicle *v'* inside an upstream or downstream hub. Constraints (34) ensures that if a vehicle does not pick up products at a hub, the quantity of products transferred to this vehicle is null. Constraints (35) and (36) ensure that if the quantity of products in a vehicle leaving a hub is greater than the quantity of products when it enters this hub, the vehicle must take some products from another vehicle in this hub. The constraints (37) and (38) ensure that if there is a transfer from one vehicle to another, the first one arrives before the latter leaves.

$$x_{ij}^{v} \in \{0;1\}, \forall i \in O,\ \forall j \in O \cup USH, \forall v \in V \tag{39}$$

$$x_{ij}^{v} \in \{0;1\}, \forall i \in USH,\ \forall j \in DSH, \forall v \in V \tag{40}$$

$$x_{ij}^{v} \in \{0;1\}, \forall i \in DSH,\ \forall j \in D \cup DSH, \forall v \in V \tag{41}$$

$$y_{ij}^{vk} \geq 0, \forall i, j \in O \cup USH \cup DSH \cup D, \forall v \in V, \forall k \in K \tag{42}$$

$$a_{i}^{v}, b_{i}^{v}, w_{i}^{v} \geq 0, \forall i \in O \cup USH \cup DSH \cup D, \forall v \in V \tag{43}$$

$$z_{ik}^{vv'} \geq 0, \forall i \in USH \cup DSH, \forall k \in K, \forall v, v' \in V, v \neq v' \tag{44}$$

$$u_{ik}^{v} \in \{0;1\},\ \forall i \in USH \cup DSH, \forall\ k \in K, \forall v \in V \tag{45}$$

$$r_{i}^{vv'} \in \{0;1\},\ \forall i \in USH \cup DSH, \forall v, v' \in V, v \neq v' \tag{46}$$

Constraints (39) to (46) represent the binary and non-negativity restrictions imposed on the decision variables. Constraints (39) to (41) force the vehicle to pass through the upstream and downstream hubs because of the absence of arcs between the suppliers (*O*) and the customers (*D*).

Example of Application, Scenarios and Results

To illustrate the proposed methodology, the authors use the model defined above to assess cost and total emissions for different scenarios. In other words, the authors propose, for a real case (concerning a set of shippers, sea lines and road transport carriers), a set of collaboration scenarios which are assessed using

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the proposed model. Those scenarios express shippers' collaborative transportation planning strategies with transhipments; the authors estimate for each of them total emissions, total transportation cost and total distance caused by food distribution.

To define scenarios, real data was collected on a set of shippers located in the UK and delivering to customers in continental Europe. The customers' demand collected varies according to the company and the time the authors consider is the period between January 2014 and June 2014. The data file contains:

- The name of the supplier
- The collection date and the collection point
- The delivery date and the delivery point
- The number of pallets required per each customer

Following are the additional data used in the model:

- Real distances are provided, and travel time between each pair of sites as well.
- The list of ports in England and continental Europe with the connections allowed between these ports are given.
- Vehicles have a capacity of 24 pallets.
- The emissions coefficient per kilometre for an empty truck taken into account is 0.767 $kgCO_2$/vehicle.km.
- The emissions coefficient per kilometre pallet added in a truck is 14 gCO_2/pallet.km.
- The cost per kilometre per vehicle is 0.525€/km.
- The cost per hour per vehicle is 21.67€/km.
- The fixed cost per vehicle is 156.81€.
- The type of boats used between the ports is ro-ro ships (roll-on, roll-off).
- The emissions coefficient per kilometre pallet in a ro-ro ship is 14.4 gCO_2/pallet.km.
- For simplification, the costs are calculated by the same way whatever a shipment is on a boat or on the road.

Scenario Construction and Experimental Study

From those data, three main groups of scenarios are defined. The customers' demand as well as the transportation system remain the same; the differences between each of the three scenarios is the importance given to economic and environmental criteria, translated in the model by the values of parameters α and β.

More precisely, in the variant scenarios 1a, 2a and 3a, the authors fix the value of α to 1 and β to 0. This corresponds to the minimization of emissions only. In the variant scenarios 1b, 2b and 3b, the authors fix the value of α to 0.5 and β to 0.5. This corresponds to the minimization of both emissions and costs at the same time. Finally, in the variant scenarios 1c, 2c and 3c, the authors fix the value of α to 0 and β to 1. This corresponds to the minimization of the cost only.

This case study is solved using the model presented in section 3. The model is solved with CPLEX 12.5 on a Quad core CPU (2.3GHz) and 8GB of RAM. This problem is NP-hard and complex to solve. So, a time limit of one hour is fixed. The gap between the best solution found by CPLEX (the upper bound) and the lower bound varies between 0% and 4.5%. The average gap is 1.5%. The simulation is made day by day for the period between January 2014 and June 2014. The model is run one time for

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each day. During a day, all the 72 customers are not served. In average, 10 customers are served within a day. After using the model, routes respecting the scenarios are created to deliver customers and optimize the load fill of the trucks for a specified day. The daily results of a month are aggregated to produce monthly results. The results are also the total results for the three suppliers so the authors can compare the scenarios without collaboration with the scenarios with collaboration.

RESULTS AND DISCUSSION

To compare two scenarios' emissions (costs), the authors use the average relative gap between two scenarios, i.e., the percentage difference between the emissions (costs) of both scenarios and

$$gap = 100 * \frac{S1 - S2}{S1}$$

where S1 is the emissions (cost) of the first scenario to compare and S2 is the emissions (cost) of the second scenario to compare. Without collaboration between the companies, the best scenario is scenario 1a. When scenario 1 and scenario 2 are compared, the average reduction of emissions is 8.96% for the variant a, 10.25% for the variant b and 9.58% for the variant c. When scenario 1 and scenario 3 are compared, the average reduction of emissions is 11.8% for the variant a, 11.27% for the variant b and 11.2% for the variant c. Here the collaboration can improve the green efficiency of the transportation planning of the three suppliers in terms of CO_2 emissions. When scenarios 2 and 3 are compared, the average reduction of emissions is 3.12% for the variant a, 1.14% for the variant b and 1.79% for the variant c. While collaboration without transhipments already improves the transportation planning, it can be more improved by implementing transhipment.

Collaboration is also a way to decrease the total transportation cost. The average reduction is 10.57% between scenarios 1a and 2a, 9.59% between scenarios 1b and 2b and 8.66% between scenarios 1c and 2c. The transhipment can also decrease the total transportation cost; indeed, the average reduction is 6.54% between scenarios 2a and 3a, 2.57% between scenarios 2b and 3b and 3.61% between scenarios 2c and 3c. The results are provided in the Appendix in table 2 where C is the cost, E are the emissions and D is the distance.

Table 1 presents the results for the six months. On average, whatever the values of α and β, for scenario 2, the emissions reduction is 9.4% and the costs reduction is 9.8% compared to scenario 1. For scenario 3, the emissions reduction is 11.9% and the costs reduction is 13.4% compared to scenario 1. These results can be explained by the fact that collaboration improves the filling rate of the vehicles. In fact, by consolidating the shipments from several suppliers, fewer vehicles are used to transport these

Table 1. Average results of all the variants for each scenario

	Scenario 1	Scenario 2	Gap	Scenario 3	Gap
Emissions (kg)	513,458	465,011	9.4%	452,530	11.9%
Costs (€)	509,474	459,584	9.8%	441,307	13.4%

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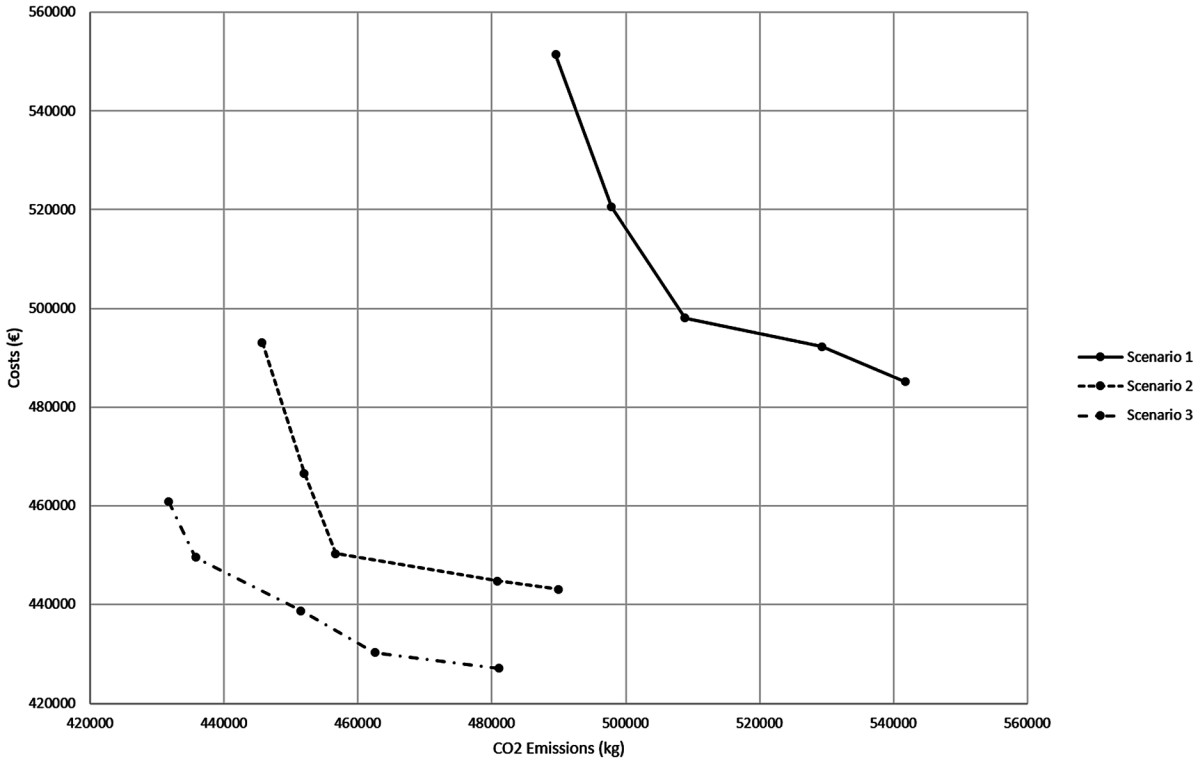
shipments and the total distance travelled by all the vehicles is also reduced. As total cost and emissions are strongly related to the distance, by reducing the total distance, costs and emissions are also reduced.

Figure 5 represents the total costs depending on the total emissions for the three scenarios. Two more variations for the values of α and β are added. For all the scenarios, for each point from the left to the right, the values of the parameters are:

α=1 and β=0 (variant a)
α=0.75 and β=0.25
α=0.5 and β=0.5 (variant b)
α=0.25 and β=0.75
α=0 and β=1 (variant c)

Scenario 3 is always beneficial. Also, in variant c, the costs are slightly better than in variant a (since costs are minimized in variant c) but the emissions are a little higher. This is because, contrary to the emissions, the costs are not only related to distance but also to time. In fact, vehicles have also a fixed cost, so when total costs are minimized, fewer vehicles are used, but the distance travelled can be slightly higher so the emissions are bigger too.

Figure 5. Total costs depending on total CO_2 emissions



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After the simulations were conducted, discussions took place with the three companies. When seeing the results of simulations, the three operational teams sought to physically consolidate part loads from the UK to the European continent. In order to implement the collaboration, on a daily basis, the operational teams had to perform tasks including:

- Creating and validating the orders within a common tool for the three companies
- Assessing the orders for consolidation opportunities
- Proposing the consolidation opportunities to the three companies and the executing carrier
- Planning the orders in a joint fashion
- Executing the order

The team providing operational execution found this new way of considering logistics provision both challenging and interesting. But in practice there are a number of practical constraints which prevented consolidation opportunities from materializing. These included the following:

- Production & Manufacturing: changes to collection times that conflict with stock availability
- Consumers: changes to delivery times that conflict with site opening times and/or tight production schedules
- Third-party carriers: additional delivery distances that carriers are unable to fulfil on the day of placing the order
- Third-party carriers: delivery vehicle specification for certain delivery points
- Operational: objectives not always aligned to customer commercial pressure and certain account management objectives
- Consumers: operational conflict with last-minute order fulfilment requirements

CONCLUSION

The collaboration in supply chains is becoming more and more important for companies especially when it produces positive effects on the sustainability of the supply chain. In this paper, the authors presented a new MIP model for a variant of the PDPTTW where products have to pass through exactly two transhipments points between their origin and their destination. They used this model to study the benefits of collaboration with and without transhipment. They applied it on a case study in a short-sea-shipping context. Thanks to the real case study, the model has been tested on real data. The authors succeeded in showing the positive impact of this collaborative approach in terms of reduction of total transportation cost and CO_2 emissions. Moreover, the potential of the collaboration can be increased by using transhipment in certain nodes of the network. The numerical contribution of the paper is useful for showing the role of collaboration and transhipment to develop the green transportation planning.

However, the experimental study should be more detailed. In fact, the only variable parameter here is the demand. The location and number of sites are always the same. A future work could be directed to conduct more simulations with more variable parameters such as the number of suppliers and customers, the location of sites or the characteristics of the vehicles, among others. The authors expect also to take into consideration more constraints such as capacity of hubs or the operating costs inside hubs. Finally, due to the combinatorial complexity of the problem, the elaboration of heuristics and meta-heuristics could be an interesting perspective of research as well.

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APPENDIX

Table 2. Total results for the six months of data

Month		Scen 0	Scen 1a	Scen 2a	Scen 3a	Scen 1b	Scen 2b	Scen 3b	Scen 1c	Scen 2c	Scen 3c
Jan 2014	C (€)	96572	72967	70626	68682	66814	64657	63672	64945	62732	61607
	E (kg)	82074	69496	67721	66225	72603	70221	68994	76862	74342	73685
	D (km)	85809	68010	65395	63563	71163	67897	66195	75223	71763	70824
Feb 2014	C (€)	112769	99856	89458	85532	90945	82483	80322	89174	81176	78857
	E (kg)	93756	84133	78253	75959	87247	79801	79870	93516	86379	82441
	D (km)	100201	86036	77865	74921	89221	79117	79032	95107	85395	81294
Mar 2014	C (€)	129208	99319	92588	86130	89762	86655	83279	88450	85812	82371
	E (kg)	106144	87309	81462	78732	89062	82671	82507	92498	87565	86761
	D (km)	114807	88153	80564	76834	89379	81275	80831	92648	86580	85251
Apr 2014	C (€)	136254	96286	77702	71377	88897	70233	68798	85789	72266	66813
	E (kg)	107777	86546	71033	68407	90284	73694	72017	94088	77041	76909
	D (km)	121068	92611	71804	68507	96373	74408	72534	100141	78228	77359
May 2014	C (€)	106251	77720	71992	66088	71057	63648	61737	68407	61513	59806
	E (kg)	85345	65201	60978	58155	69668	61660	60356	75260	68537	65633
	D (km)	94409	66198	61109	56755	70844	60623	59177	75904	67480	64132
Jun 2014	C (€)	131499	105257	90734	83022	90597	82630	80915	88368	79612	77651
	E (kg)	110542	96837	86228	84287	99964	88635	87741	109569	96031	95676
	D (km)	116843	97293	83369	80659	99524	85519	84258	109713	93530	92161
Total	C (€)	712553	551405	493101	460830	498073	450306	438723	485133	443110	427104
	E (kg)	585638	489522	445674	431765	508829	456683	451486	541794	489895	481105
	D (km)	633135	498300	440107	421239	516504	448839	442026	548736	482977	471021

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Chapter 7
A Balanced Scorecard Framework for Measuring Sustainability Performance of Business Organizations

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ABSTRACT

Sustainability is about meeting the needs of today without compromising the needs of future generations. It involves focus on three main dimensions, economic, environmental, and social, for achieving overall performance. Majority of the companies are adopting sustainability for business growth and boosting their corporate image for long term competitiveness, thereby receiving financial benefits as well. Sustainability is a concept that has come into picture a few years back and presently making a big mark in every field. A balanced scorecard framework is proposed for measuring sustainability performance of business organizations. Four main dimensions are considered, namely organization, process, core, and learning. Each of these dimensions comprises of various indicators obtained from global reporting initiative (GRI) and corporate social responsibility reports. The application of the sustainability scorecard is performed via multi criteria decision making technique called analytical network process (ANP). A numerical study is provided.

INTRODUCTION

Sustainability is about meeting the needs of today without compromising the needs of future generations. It requires the integration of environmental, economic and social priorities. Now the question arises why the companies or bigger firms are looking forward or investing in the sustainability, the concept or term that was no-where a few years back but presently making a big mark in every field.

According to a global survey by Mckinsey and Company (2010), "More than 50 percent of executives consider sustainability- the management of environmental, social and governance issues-"very" or

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"extremely" important in a wide range of areas, including new product development, reputation building and overall corporate strategy". The result shows the top reason for adopting sustainability is managing or improving corporate reputation that is directly linked with the business point of view, more positive the image of the company more investors it can attract . The other reasons to invest in sustainability can be meeting customer expectations, to have a competitive edge, leadership etc. No doubt, going green comes with a cost. However, the long term benefits and business advantages overpowers the initial costs. According to a business review by Harvard (2012) " In the past decade, investor demand has increased transparency and communication, creating a large and growing pool of data on corporate sustainability". Sustainable management practices and sustainable products or services open up a new source of revenues and new markets, therefore bringing new business models with high involvement of sustainability in the corporate strategy (Mota et al 2015). Stakeholders and societies value companies that believe in developing sustainably. In fully realizing the sustainability or the sustainable development, sustainable design has an important role to play (Küçüksayraç, 2015). Some of the drivers of the sustainable development are; customer demands, government regulations, industrial sector initiatives etc. The research study shows the most important drivers for sustainable development are boosting "brand value" and "reputation of the firm". According to a study by Massachusetts Institute of Technology (2012) "Sustainability is Profitable", survey done in collaboration with Boston Consulting Group, gathered more than 4000 responses from executives and managers across all industries and regions. The overall results show that companies are taking sustainability seriously and reaping financial benefits with the adoption of the sustainable business practices Consumer wants to know each and every aspect of the product or service they use and how it impacts the environment and human well-being that- gives rise to the sustainability.

Problem Definition

The growing importance of the social and environmental issues in last few decades has put a lot of pressure on the companies to consider these factors in addition to the existing ones. The environmental and social factors are often not linked to the economic success of the firm and the interaction of all three remains unclear. This lack of integration turns out to be an obstacle for firms aiming to achieve simultaneous improvement of economic, environmental and social performance of business. The environment perspective should be deep embedded in the strategy. Managing environmental issues requires much more than just adding an environmental perspective in the existing strategy. Treating all the issues related to sustainability separately even in its own dedicated prospective will lead to isolation and finally crashing the whole cause. Sustainability associated with financial, learning, customer and internal growth processes should be put in the objectives within the process to bring them out as a set. The aim of the research is to develop a sustainability scorecard framework to measure the sustainability performance of business organizations. To achieve this goal, following problems have been addressed:

1. Identifying criteria for measuring sustainability performance.
2. Developing a sustainability scorecard for measuring sustainability performance.
3. Evaluating the sustainability performance of business organizations

The first problem involves the identification of indicators that can be used for measuring the sustainability of business organizations.

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The second problem involves the development of the sustainability scorecard based on indicators identified in step 1.

Thirdly, the proposed sustainability scorecard framework is applied using multi criteria decision making technique- Analytic Network Process (ANP) to evaluate the sustainability performance of business organizations.

The rest of the chapter is organized as follows. The next section is the literature review followed by the solution approach and numerical application. The final section draws the conclusion.

LITERATURE REVIEW

Business Performance Measurement (BPM)

A business should closely measure and manage its success to ensure if the set objectives are being met timely. Using performance management systems are a great way of recording the business health and suggesting future improvements. It gives all the vital information that leads to implementation of the strategies for growth and competitiveness. BPM's helps to choose key performance indicators (KPI's) to measure and suggest improvements and helps to keep main points in mind when setting business targets. Business performance measurement is required to know:

1. How well an Organization is progressing with respect to their missions and goals?
2. What should be measured? How to set KPI's? How important is the measurement?
3. When should the return be expected?
4. How the performance is reported internally?
5. Where should be the focus to achieve sustainability in long run?
6. How an Organization can most effectively measure performance and stay competitive?

Sustainability in Performance Management

Sustainability can drive significant business benefits. However, in many organizations its value is not fully realized. Sustainability, when integrated with the corporate strategy and operations can drive value through:

1. Revenue generation: new products, services and markets.
2. Cost control: resource efficiency, low energy consumption and waste minimization.
3. Reputation building: enhancing brand value and promoting a positive culture.
4. Risk management: by complying with rules and regulations.

"Sustainability and the value it creates must be quantified and linked to the business performance if the case for sustainability is to be made and the benefits are to be realized" (Accenture sustainability performance management report, 2011).

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Why Sustainability Is Vital for Business Performance?

Sustainability in business was traditionally an item on the corporate social responsibility reports of the companies but now this has turned to be an opportunity. Investors see the risks in companies that are depleting the natural resources through wastewater, emissions, not nurturing the talent etc. According to the UN Global Compact-Accenture CEO (2) "We are moving towards an era in which businesses will no longer focus purely on profit and loss as the primary means of valuation but rather take into account also the positive and negative impacts on society and environment."

Tools for Sustainability Performance Measurement

Sustainability can be developed along three dimensions i.e. environment, social and economic, therefore there are different assessment tools for each dimension. Below are some of the tools that can either be used individually or combined with other techniques for sustainability measurement.

1) Decision Making Tools

These are the tools that are used to select a course of action among several possible alternatives. Some of the tools that are actively used by the business organizations are:

a. ISO 14001: ISO 14001 first published in 1996 was developed to provide an environmental management system to help organizations reduce their environmental impact. The drivers of adopting ISO are improving environmental performance and matching competitor's actions (Prajogo et al, 2012). The factor that effects the implementation of ISO is-not enough emphasis on substandard processes by ISO.
b. Life Cycle Assessment: LCA methods are used for addressing social, economic as well as environmental problems. (Clune & Lockrey, 2014) introduces a process to develop environmental strategies by using LCA and design thinking. "LCA is the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO 14040:2006). There are four steps involved in the LCA technique namely goal and scope definition, inventory analysis, impact assessment and interpretation of the results. The weakness of the LCA is that it requires a lot of time and very complex data gathering.
c. Multi Criteria Decision Making Tools: (Milutinović et al, 2014) talks about the importance of the multi criteria tools when a lot of criteria are involved in the assessment of sustainability. These tools make it possible for the user to consider large amounts of data, objectives and other information that is required to tackle with real world complex problems (Egilmez et al, 2015). ANP is an alternative to other multi criteria approaches as it allows users to incorporate interdependencies among nodes and clusters (Lin et al, 2015).
d. Indicators for Sustainability Assessment: The research study by (Moreno & Fidélis, 2015) explores the importance of setting up of indicators for sustainability assessment. It describes the sustainability indicators on environment, social and economic issues and explain the major driving forces of those indicators.

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e. Sustainable Value Stream Mapping: It is built upon the traditional value stream mapping which is based on reducing non-value added activities and focuses on lean manufacturing. The research study by (Brown et al, 2014) explores how sustainable value stream mapping can be used in the different industries.

2) Environmental and Sustainability Reporting

GRI: Global Reporting Initiative (GRI) is a leading organization in the sustainability field. GRI promotes the use of sustainability reporting as a way for organizations to become more sustainable and contribute to sustainable development. More than 4,000 organizations from 60 countries use the guidelines to produce their sustainability reports. More and more companies are publishing their reports based on the GRI indicators (Chen et al, 2014).

Challenges in Sustainability Measurement

a. GRI reporting system is currently the most widely used tool for sustainability reporting. A single reporting system can't be sufficient to satisfy the needs of large industrial sector, so a gap will always exist between the current reporting system and the dynamic needs of various industrial sectors (Brown et al., 2009).
b. Integration of sustainability with the strategy and aligning its principles with the core value of the organization can be a challenge for business organizations.

Balanced Scorecard Approach for Business Performance Measurement

A scorecard is a statistical tool that is used to measure and report the progress towards the achievement of a particular goal in a structured way. It provides visually appealing summary that conveys overall success or failure of an organization (Niven, 2006). Balanced scorecards are considered as one of the best tools for measuring the performance of a business organization. It helps report performance in a structured way. Balanced scorecards are flexible and provide overview of the organizational performance and can be integrated with other measures. Scorecard is based on collection of key performance indicators (KPIs).

Why Balanced Scorecards Are Used?

Efficient performance management systems act as a useful tool that helps to monitor and control the firm's performance (Lin et al., 2014). The basis of the balanced scorecard is that no single measure can tell the whole performance. A competitive strategy combined with the balanced scorecard can have a significant impact on the firm performance.

Strengths

1) The organizational units can improve themselves with the feedback mechanisms of the balanced scorecards.
2) Balanced scorecard implements the strategy that is converted in to performance metrics. They are developed in a way that specifically directs attention to the strategy and future direction.

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Weaknesses

1) The balanced scorecard relies on a well-defined strategy without proper execution of the strategy the implementation could fail.
2) All the stakeholders are not involved - that may be important to some organizations for performance measurement.
3) Use of generic metrics in the Balances Scorecard makes it harder to use.

How Balanced Scorecards Are Used?

1) Develop Strategy: The first step is the development of the strategy which would serve as the base to all the four perspectives. In this step mission is clarified and it is important to align the vision.
2) Plan Strategy: The second step for the execution of the balanced scorecard is to plan the strategy-strategy maps are created and the targets are selected and measured.
3) Aligning Organization: The third step in the balanced scorecard execution is to align the organization. The strategy should be communicated - business units, support units should be aligned with the corporate strategy.
4) Operations Planning & Reporting: is the fourth step in the strategic balanced scorecard execution, which focuses heavily on improving the key processes and understanding of process improvements are critical for effective strategy implementation.

Sustainability Balanced Scorecard

Sustainability balanced scorecard is an internal management tool to operationalize sustainability goals from company's strategic plan (Cerf, 2007). Sustainability balanced scorecard integrates social, economic and environmental aspects with the existing perspectives (Learning, Internal, Financial, Customer). Sustainability management with the balanced scorecard helps to overcome the shortcomings of conventional approaches to environmental, economic and social management systems by integrating the three pillars of sustainability into a single tool (Figge et al., 2002).

SOLUTION APPROACH

In this chapter, the solutions of the problems explained in the earlier chapter are presented. Solution approach – (Figure 1) comprises of three main steps:

1. Identifying criteria for measuring sustainability performance.
2. Sustainability scorecard development for measuring sustainability performance of organizations.
3. Application of sustainability scorecard for evaluating sustainability performance of business organizations using multi criteria decision making approach called ANP.

These steps are explained in detail as follows:

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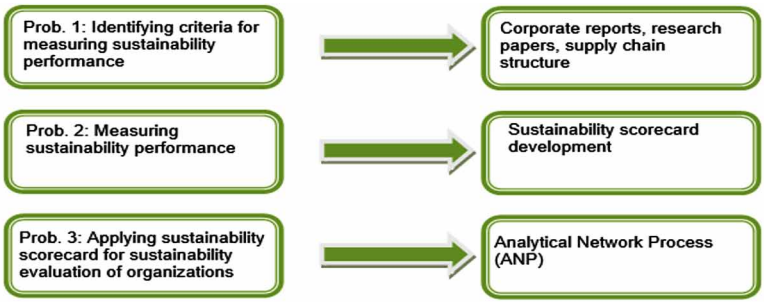
Figure 1. Solution approach



Identifying Criteria for Measuring Sustainability Performance

To measure the sustainability performance of business organizations, key performance indicators for measuring business sustainability are identified and improvements are suggested. The supply chain structure, the corporate social responsibility reports (CSR) of the most sustainable organizations and the research papers have been studied to identify KPI's. Following indicators are being focused upon by businesses for effective improvements:

1. Management
2. Employees
3. Operations
4. Quality
5. Sales and Marketing
6. Service and Growth
7. Distribution Network
8. Sustainability

Table 1 shows all the indicators mentioned above with references. The core indicators that are found to be common in the CSR reports of 10 most sustainable companies have been discussed. (*The list is*

Table 1. Indicators and references

Indicators	References
Management	CSR (Cenovus, Centrica PLC), (Friebel & Schweiger, 2012)
Employees	CSR (Johnson & Johnson, Cenovus energy, Centrica PLC, Monsanto)
Operations	CSR (Adidas, Biogen Idec, Cisco Systems, Johnson & Johnson), (Fullerton, Kennedy, & Widener, 2014)
Quality	CSR (Johnson & Johnson), (Pereira-Moliner, Claver-Cortés, Molina-Azorín, & José Tarí, 2012)
Sales and Marketing	(Hasan & Ali, 2015; Rouzies, Anderson, Kohli, Barton, & Zoltners, 2005),
Service and Growth	CSR (Natura Cosmetics, Sage Group PLC)
Distribution Network	CSR (Coca-cola, Bombardier, Nestle SA, Umicore)
Sustainability	CSR (Most sustainable Companies- by corporate Knights)

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Table 2. Core indicators and references

Indicators	References
Continuous Improvement	CSR (Biogen Idec, Outotec, Statoil, Neste Oil OYZ, Novo Nordisk, Adidas, Umicore), (Terziovski,2010 ; Zain & Kassim, 2012)
Collaboration	CSR (Outotec, Biogen Idec, Stat oil, Neste oil OYZ, Adidas, Umicore), (Chakraborty, Bhattacharya, & Dobrzykowski, 2014; Liao & kuo, 2014; Trencher, Yarime, & Kharrazi, 2013)
Innovation	CSR (Biogen Idec, Natura Cosmetics, Outotec, Statoil, Neste Oil OYZ, Adidas, Umicore), (Leal-Rodríguez, Eldridge, Roldán, Leal-Millán, & Ortega-Gutiérrez, 2015)
Leadership	CSR (Westpac Banking, Biogen Idec, Outotec, Statoil, Neste Oil OYZ, Novo Nordisk, Adidas, Umicore)

announced by Corporate Knights- a Toronto based Media Agency,) .The indicators presented in Table 2 are considered as vital for the success of any business organization and are focused upon by 10 most sustainable organizations.

Sustainability Scorecard Development for Measuring Sustainability Performance of Business Organizations

A sustainability scorecard framework is developed that can be used by the business organizations to measure sustainability. The indicators that are being focused upon by businesses to suggest effective improvements have already been presented.

Justification of Sustainability Scorecard

Currently, sustainability balanced scorecard and other scorecards are being used in the organizations to measure sustainability but no scorecard provides complete overview of the internal indicators of the organizations as the indicators need to be customized. No doubt the balanced sustainability scorecard integrates sustainability using the four perspectives of the balanced scorecard, however it is important that the sustainability should be deep embedded in to the strategy than being an individual prospective. All the indicators presented in the model can be divided in four wide categories: organization, process, core and learning. Sustainability has been integrated in all of the categories.

Figure 2 shows sustainability scorecard

Figure 2. Sustainability scorecard

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Explanation of Indicators

1. **Continuous Improvement:** Is an ongoing or never-ending effort to improve products, services or processes. The customer's expectations are rising and the competition is increasing. Firms needs to continuously improve to remain in business (Zain & Kassim, 2012). "The adoption of continuous improvement and innovation management strategies is a critical factor for high performing SME's to achieve strategic goals and objectives" (Terziovski, 2010).
2. **Innovation:** Is a new idea, device or process. "Innovation can be viewed as the application of better solutions that meet new requirements, in articulated needs or existing market needs and this is accomplished through products that are more effective, processes, services, technologies or ideas that are readily available to markets, governments and society"(3). The greater the ability of a firm to update their knowledge over their competitor's, the more it would help the firm to improve its performance in the innovation race (Leal-Rodríguez et al., 2015).
3. **Collaboration:** Is a working practice where different individuals work together to achieve a common benefit. Collaboration is the way of overcoming current challenges and have the potential to deliver the products that are sustainable and of the excellent quality on time. Collaborations can help firm achieve competitive position by reducing costs and firms can manage risk more efficiently by sharing (Chakraborty et al., 2014). Collaborations for environment are highly successful. (Trencher et al., 2013) demonstrates how the successful universities collaborations with industries, communities or government can contribute to the sustainability.
4. **Leadership:** Is a process of social influence and motivating the team members to achieve the common goal. An effective leader is a person who has a vision and can inspire people and align them to his vision. A leader can coach and build a team so as to achieve the target.
5. **Management by Objectives:** Is a process of defining objectives within an organization so as to achieve the objectives set by management" (4). The personal goals set for planning by the employees should align with the organization goals. (Friebel & Schweiger, 2012) establishes a connection between management quality and firm performance.
6. **Employees:** Are the core and the integral part of any successful organization. Often new ideas and innovations are generated by the employees that lead to the company's growth. Westpac Banking believes in the training of the employees, equal opportunities and diversities in the workforce.
7. **Operations**: The value to a business is delivered when the operations transform the resources in to goods or services to generate revenues. The operations are widely divided in to three broad categories namely: streamlined manufacturing, supplier relationship management and waste management.
    a) Streamline stands for optimizing the business process by reducing wastes and eliminating movement and unnecessary processes. (Fullerton et al., 2014) talks about adoption of lean manufacturing as a holistic approach and studied its impact on the firm performance.
    b) **Supplier Relationship Management (SRM)**: The supplier relationship management helps the organization to maximize the relationships with the supplier and minimize the overhead costs. Businesses have become very competitive and challenging, so a strong and strategic relationship with supplier is required for strong corporate performance (Liao & kuo, 2014).
    c) **Waste Management**: Is the act of preventing on the first step or treating the solid industrial wastes. Not managing the industrial wastes carefully is a bigger waste in itself that can lead to health and environment effects.

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8. **Quality**: Is the ability of a product or a service to meet or exceed customer requirements or expectations, quality is customer dependent. Producing high quality products are very critical to achieve market success with. (Pereira-Moliner et al., 2012) shows - environment management can play the mediating role between the two.
9. **Sales and Marketing**: Sales is the exchange of the commodities for money. (Rouzies et al., 2005) explains the value of integration of sales and marketing to create more value to the firm which can-not be created alone either by sales or marketing, they work together the best when they are supportive of each other. (Hasan & Ali, 2015) explains the impact of green marketing on the firm's performance.
10. **Service & Growth**: Customer service in addition with the superior products or service is critical to the business growth. The purpose of superior customer service must be, not only to understand customer concerns but also to anticipate customer requirements. Customer service can provide the insight into customer's unspoken requirements Neste Oil OYZ identifies that customers growing demand for the high quality.
11. **Distribution**: Is the process of moving a product from the supplier stage to the customer. It drives the overall profitability as it is related to both the supply chain as well as the customer experience (Chopra, 2013). Designing an effective distribution network is very important to be on the competitiveness forefront.

Sustainability in Business

Business sustainability is often defined as "managing the triple bottom line – a process by which companies manage their economic, social and environmental risks, obligations and opportunities" (5). GRI (G3) indicators reported by the most sustainable companies (Top 5 by category are presented in Table 3) have been studied and are summarized in Table 4. Best of 3 "Yes" responses have been considered e.g. if 3 or more companies are reporting on a G3 indicator it's a "Yes" and that indicator is presented in summary Table 4 against the company's category (or area of function). Similarly all G3 indicators have been analyzed. The GRI indicators are divided in to 3 categories namely: Environment with 30 indicators, Social with 39 and Economic with 9.

Summary: The summary Table 4 shows the list of the environmental, social and the economic indicators that each company in their respective category is reporting. This table can be used as a benchmarking tool by the new companies that are looking forward to make in to the list of most sustainable companies.

From Table 4 it can be concluded that some indicators are commonly reported i.e. EN (1, 2, 3, 8 and 9), LA (1, 2, 7, 8, 11 and 13), HR (2, 5, 6, and 7), SO (1, 2, 3, 4 and 5), PR (1, 3, 5, 6 and 9), EC (1, 2, 3, 8 and 9) and are used in sustainability balanced scorecard framework.

Applying Multi Criteria Decision Making Approach ANP for Evaluating Sustainability Performance of Business Organizations

ANP is the method used to evaluate the indicators. It is a multi-criteria decision making approach for evaluating alternatives against a pre- defined set of criteria by a committee of decision makers. ANP is the generalized form of the analytic hierarchy process; priorities are established the same way as that of AHP using pair wise comparisons. ANP is capable of taking inter-relationships of correlations among

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Table 3 Most sustainable companies by category (Corporate Knights 2014)

Ranking	Name of the Company	Category
1 17 19 30 31	Westpac Banking Keppel Land Limited Australian and New Zealand Banking Group Shinhan Financial Group Co. Ltd Hang Seng Bank Ltd.	Financials
2 7 18 21 57	Biogen IDEC Novo Nordisk UCB SA Life Technologies Corporation Johnson & Johnson	HealthCare
3 10 14 24 27	Outotec Schneider Electric Aeroports de Paris Bombardier Siemens AG	Industrial
4 6 51 52 53	Statoil Neste Oil OYZ Royal Dutch Shell PLC Cenovus Energy Suncor Energy INC	Energy
5 11 15 16 34	Dassault Systems SA Cisco Systems ASML Holding NV The Sage group PLC Samsung Electronics CO Ltd	IT
8 13 22 35 60	Adidas Bayerische Motoren Werke AG Tim Hortons Wolters Kluwer NV Daimler AG	Consumer Discretionary
9 12 20 28 27	Umicore BASF SE Sigma Aldrich Corporation Croda International PLC Monsanto Company	Materials
23 43 45 86 92	Natura Cosmeticos SA Coca Cola Enterprises Inc. L'Oreal SA Nestle SA Wesfarmers Ltd.	Consumer Staples
26 47 62	Centrica PLC Duke Energy Corporation Acciona SA	Utilities
29 40 70 73	Star Hub Ltd Vivendi SA Telus Corporation BCE INC	Telecommunication Services

criteria into account. The fundamental weight of scale used for the pair wise comparison is: 1 being Equal Importance to 9 being Extreme Importance.

The steps of ANP are (Yang et al., 2013; Yazgan & Ustun, 2011);

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Table 4. Summary of indicators

	Environmental	Social	Economic
Financials	EN(1,2,3,4,5,6,7,8,9,16,17,18, 19,21,22,25,26,28)	LA(1,2,3,4,5,6,7,8,9,10,11,12,1 3,14) HR(1,3,4,5,6,7,8) SO(1,2,3,4,5,7,8) PR(3,5,6,7,8,9)	EC(1,2,3,4,5,6,7,8,9)
HealthCare	EN(1,3,4,5,6,7,8,9,16,17,18,2 2,23,24,26,28,29)	LA(1,2,3,4,6,7,8,10,11,12,13) HR(2,3,5) SO(1,2,3,5,6) PR(1,3,5,6,7)	EC(1,2,3, 8,9)
Industrials	EN(3,4,5,6,7,8,16,17,18,19,20 ,22,23,26,28)	LA(1,2,4,7,8,10,11,12,13) HR(1,2,3,5,6,7) SO(1,2,3,4,5,6,7,8)PR(1,2,3,4,5,9)	EC(1,2,3, 6,7,8,9)
Energy	EN(1,3,4,5,6,8,9,11,12,13,14 ,16,17,18,19,20,21,22,23,25, 26,28,29)	LA(1,2,4,7,8,11,12,13,14) HR(1,2,5,6,7,8,9) SO(1,2,3,4,5,6,7,8) PR(1,3,9)	EC(1,2,3, 4,6,7,8,9)
IT	EN(1,2,3,4,5,7,8,11,16,17,18, 19,20,22,26,28,29,30)	LA(1,2,6,7,8,10,11,13) HR(4,5,6,7) SO(1,2,3,4,5,7,8) PR(1,2,5,6,7,9)	EC(1,9)
Consumer Discretionary	EN(1,2,3,4,5,6,7,8,9,10,12, 16,17,18,19,20,21,22,25,26, 28,29)	LA(1,2,3,4,5,6,7,8,9,10,11,12,1 3,14) HR(1,2,3,4,5,6,7,9)SO(1,2,3,4,5,6,7,8) PR(1,2,3,4,5,6,7,8,9)	EC(1,2,3, 4,5,6,7,8)
Materials	EN(1,3,4,5,6,7,8,9,11,12,16,1 7,18,20,21,22,23,26,28)	LA(1,2,4,6,7,8,9,10,11,12,13) HR(2,3,4,5,6,7,8) SO(1,2,3,4,5,6) PR(1,3,6)	EC(1,2,3, 4,6,8)
Consumer Staples	EN(1,2,3,4,5,6,7,8,9,10,11,12, 13,14,16,17,18,19,20,21,22,23 ,25,26,27,28,29,30)	LA(1,2,4,5,7,8,10,11,13,14) HR(1,2,3,4,5,6,7,8,9) SO(1,2,3,4,5,6,7,8) PR(1,2,3,4,6,7,9)	EC(1,2,3, 4,6,7,8,9)
Utilities	EN(1,2,3,5,6,7,8,9,10,11,12,1 3,14,15,16,17,18,20,21,22,23, 24,25,26,27,28,29)	LA(1,2,3,5,6,7,8,9,10,11,12,13, 14) HR(1,2,6,8,9) SO(1,2,3,4,5,6,7,8) PR(1,2)	EC(9)
Telecom Services	EN(1,3,4,5,7,8,16,17,18,19,22 ,26,28,30)	LA(1,2,3,4,6,7,8,10,11,12,13,14)HR(2,6,7) SO(1,2,3,8) PR(5,8)	EC(1,4,7, 8,9)

1. Constructing network model and structuring problem: The problem is started by constructing the network model through brain storming or other appropriate methods. The nodes in each cluster are compared with respect to the importance to the control criteria and the clusters themselves are compared.
2. Un-weighted super matrix formation: The un-weighted super matrix contains local priorities obtained through the pair wise comparisons. The pair wise comparisons with respect to criteria are done assuming the scale of 1 to 9 and their relative importance is determined and is noted.
3. Weighted super matrix formation: The weighted super matrix is obtained by multiplying all the elements in the un-weighted super matrix by the cluster weights associated with that element. In the case where all clusters are equally important, the un-weighted and the weighted super matrix are same. The process of obtaining the weighted super matrix is known as Normalization.
4. Limit super matrix formation and selection of best alternative: The weighted super matrix is raised to power of 2k+1 to achieve the convergence of importance weights, where k is an arbitrary number, the new matrix formed is called limit super matrix. When column of the numbers is same means the limit super matrix has been reached, the multiplication process is stopped and final priorities are obtained.

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Sensitivity Analyses

Sensitivity Analyses is a what-if type of analyses that allows selecting any combination of the independent variables to reflect their impact on output variables (or variables of interest). It can be nodes, super matrix entries or the individual judgements in case of ANP. The priorities of the alternatives are graphed.

Super-Decisions Software

For numerical analysis, the super decisions software developed by Dr. Thomas Saaty is used. Super decisions is based on the Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP) techniques. The super- decisions software implements the Analytic Network Process for decision making with dependence and feedback.

NUMERICAL APPLICATION

Application of Sustainability Scorecard: ANP

Analytical Network Process is applied to sustainability scorecard framework for evaluating performance of three Companies (X, Y and Z). Companies X, Y and Z are imaginative companies, and can belong to any of the category from Table 3. The ranking and prioritization of the companies are based on pair wise comparisons with respect to the indicators and finally the rankings of the companies are shown, the company with the highest rank will show the best adoption of the indicators while the company with the last rank will show the least. There are many research papers that discuss the usefulness of the integration of ANP and scorecards one being (Bhattacharya et al., 2013). The ANP technique with the feedback mechanism can overcome the traditional problems like dependency relationships and provides a systematic approach to measure interdependence. Since interactions between the indicators is the underlying principle of sustainability scorecard, ANP approach provides the flexibility for the indicators to interact with each other. Table 5 shows the list of all the indicators used for pair wise comparisons. There are a total of 109 indicators used 31 indicators are presented below while remaining 78 indicators represents sustainability (G3)

Figure Explanation

Figure 3 shows the ANP model for evaluating the companies on the basis of the indicators discussed above. The arrow indicates the connection of a node in a cluster to the other node in the another cluster known as outer dependence while the self-loop indicates the comparison of a node to another node in the same cluster known as inner dependence. The two way arrow indicates the connection from both sides in different clusters while an arrow in a single direction shows the connection from the parent node towards the children node. In the figure below the M1 indicator is connected to the 16 other indicators in the different clusters in addition to the Comp. X, Comp Y and Comp Z. All three companies are connected to all the 109 indicators and have been pair wise compared. In the comparison window (Figure 4), red arrow pointing upwards shows that top node is preferred and the blue arrow shows that left node is preferred.

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Table 5. Indicators (developed from CSR's, research papers)

Category (Number of indicators)	Sub- Category	Indicator Name	Description
Organization(7)	Management	M1	Goal Setting
		M2	Improvement Planning
		M3	Rate of Improvement
	Employees	EM1	Employee Perception and Recognition
		EM2	Employee Innovative Recommendations
		EM3	Investment per Employee
		EM4	Number of Patents/Publications per Employee
Process(15)	Operations	O1	Material Acceptance Rate
		O2	Total Spend/Sales
		O3	Defect Rate(supplier)
		O4	Supplier Involvement
	Sales & marketing	SM1	Number of Inquiries
		SM2	Profit Margin/Sales
		SM3	New Business/ Total Sales
	Service	S1	Customer Satisfaction
		S2	Customer Retention
	Distribution	D1	Costs (Inventory, Transportation, Handling & Info.)
		D2	Customer Experience
		D3	Order Visibility
		D4	Product Variety Available
		D5	Response Time
		D6	Return-ability
Core(4)	Collaboration	C1	Collaboration activities
	Continuous Improvement	C2	Continuous Improvement Activities
	Innovation	C3	Innovation activities
	leadership	C4	Leadership activities
Learning(5)	Growth	G1	Repeat Business/ Total Sales
		G2	New Product or Services
	Quality	Q1	Process Defect Rate (Sigma)
		Q2	Customer Defects/Total defects
		Q3	Service Call Rate

All the connections are done in a similar fashion, the nodes in the alternatives clusters are connected to the every indicator, so the companies can be compared pair wise with each other but with respect to all the indicators individually.

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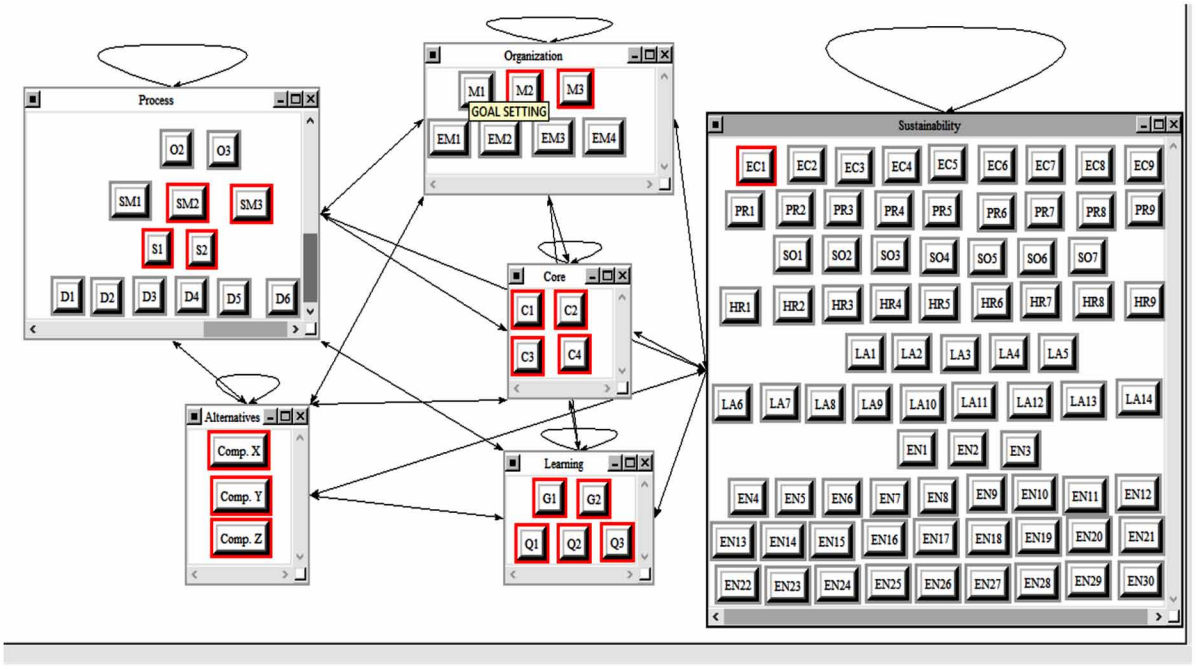
Figure 3. ANP diagram



Justification of Connections

The connections are made depending upon the factor that - if an indicator can be influenced by or it influences the other indicator in any cluster e.g. the indicator M1 (Goal setting) is connected to other indicators like M2, M3 (organization cluster), all the core indicators C1- C4 (core cluster), O4, SM2, SM3, S1, S2 (process cluster), EC1 (sustainability cluster) and the alternatives (Companies X, Y and Z). In this case, parent node is M1 while the other nodes to which it is connected act as children nodes and the comparisons have been done with respect to M1. As M1 is goal setting, it is believed that the setting of goal would have an impact on improvement planning and rate of improvement, secondly goal setting is also related to all the core indicators. Goal setting, depending upon how realistic the goal is, can lead to the profit margin and increase in the total sales, also relating to the direct economic impact generated (EC1), finally companies X, Y and Z are evaluated or ranked based on the M1 indicator. As M1 is connected to the nodes in every cluster so there will be 6 comparison windows. Table 6 shows the weight of the indicators when they are pair-wise compared with respect to M1. Similarly, all node wise connections are established.

In Figure 4, the comparison w.r.t parent node (M1) has been done for the companies (the values used are random and can be interchanged with real data). It can be noticed w.r.t to M1 indicator company Y shows the highest possibility of adoption of the indicator because of the highest value (.52642) compared to other two, but as this indicator is influenced by or it influences the other indicators it is connected to, the final values will be revealed when all the comparisons will be done.

The values used in the above comparison are just for illustration purpose. The above decisions have been made independently and the consistency of the pair wise comparisons has been checked. The

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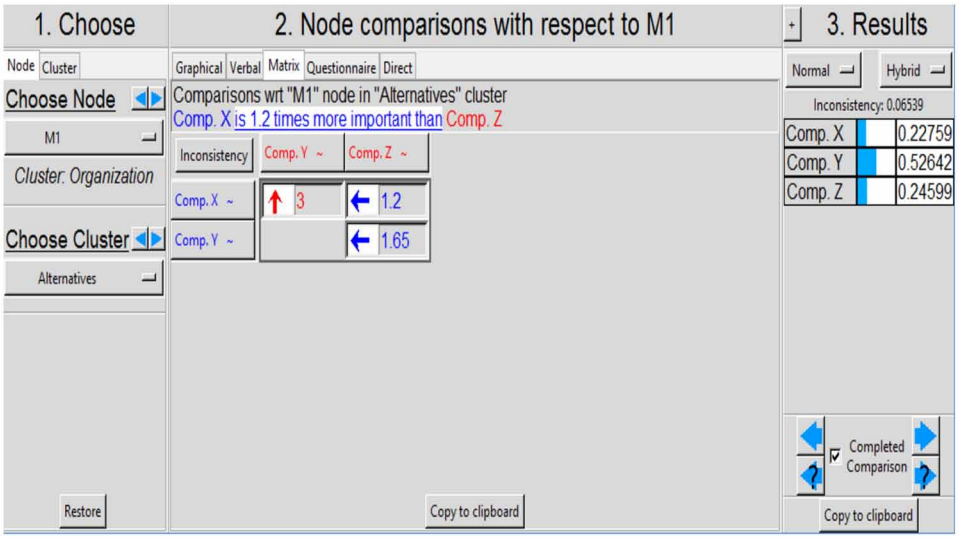
Table 6. Indicator weights

M2 (.431)	M3 (.568)	O4 (.217)	SM2 (.099)
SM3 (.284)	S1 (.210)	S2 (.188)	C1 (.233)
C2 (.185)	C3 (.221)	C4 (.358)	G1 (.227)
G2 (.169)	Q1 (.237)	Q2 (.161)	Q3 (.203)

Figure 4. Comparison window



consistency should be less than 10%. The data has been presented in the tables below after evaluating the companies X, Y and Z with respect to all 109 indicators. The values in the table below are from un-weighted super matrix only; values from weighted super- matrix aren't mentioned because cluster weights were not determined as all the clusters are considered equally important.

Numerical Values

Table 7 shows the values for the Organization, Process, Core & Learning cluster.

From the table 7 it can be concluded that:

1. Company Y has the highest values for EM1, EM2, company Z has highest value for indicators EM3, M2, M3 and Company X shows the highest value of adoption for EM4 in Organization cluster.
2. Company Z shows the highest value for the indicators D1, D2, D4, D5, D6, O2 and SM3, Company X shows the highest value for O3, S1, S2 and SM1 and Company Y - D3, O1, O4 and SM2 in Process cluster.
3. Company Y shows the maximum adoption of C1 followed by the Company X, Company Z shows the maximum adoption to C2 and C3, finally for C4 Company Y has the highest value in Core cluster.

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Table 7. Indicators values

	EM1	*EM2*	*EM3*	*EM4*	*M1*	*M2*	*M3*	*D1*
Comp. X	0.257	0.308	0.254	0.442	0.227	0.323	0.360	0.332
Comp. Y	0.444	0.419	0.211	0.280	0.526	0.322	0.171	0.313
Comp. Z	0.297	0.271	0.533	0.277	0.245	0.353	0.468	0.353
	D2	***D3***	***D4***	***D5***	***D6***	***O1***	***O2***	***O3***
Comp. X	0.254	0.382	0.360	0.258	0.343	0.305	0.303	0.454
Comp. Y	0.211	0.497	0.171	0.198	0.245	0.441	0.303	0.251
Comp. Z	0.533	0.119	0.468	0.542	0.411	0.253	0.393	0.293
	O4	***S1***	***S2***	***SM1***	***SM2***	***SM3***	***C1***	***C2***
Comp. X	0.301	0.380	0.426	0.471	0.253	0.286	0.176	0.239
Comp. Y	0.443	0.267	0.230	0.239	0.441	0.331	0.435	0.223
Comp. Z	0.255	0.351	0.343	0.288	0.305	0.382	0.388	0.536
	C3	***C4***	***G1***	***G2***	***Q1***	***Q2***	***Q3***	
Comp. X	0.260	0.284	0.254	0.258	0.249	0.322	0.277	
Comp. Y	0.217	0.435	0.305	0.198	0.177	0.322	0.138	
Comp. Z	0.521	0.279	0.440	0.542	0.572	0.354	0.583	

4. Company Z overall shows the highest value of adoption for G1, G2, Q1, Q2 and Q3 in Learning cluster.

Sustainability Indicators – G3

Table 8 shows the values for Sustainability Indicators.

From Table 8 it can be concluded that:

1. Company X shows the highest adoption of EC5, EC7 and EC9, Company Y (EC1) and the Company Z (EC2, EC3, EC4, EC6, EC8) in the Economic category.
2. Company X shows the highest sensitivity to the indicators (EN1, EN16, EN20, EN21, EN27), Company Y (EN4, EN20, EN30) and the Company Z (EN2, EN3, EN5, EN6, EN1, EN8, EN9, EN10, EN11, EN12, EN13, EN14, EN15, EN17, EN18, EN19, EN22, EN23, EN24, EN25, EN26, EN28, EN29) in the Environment category.
3. Company X shows the sensitivity to the indicators (HR6), Company Y (HR8) and the Company Z (HR1, HR2, HR3, HR4, HR5, HR7, and HR9) in the Human Rights category.
4. Company Z shows the highest sensitivity to adoption of the indicators followed by Company X and Company Y respectively in the Labour Practices and Descent Work category
5. Company X (PR5), Company Y (PR8) and Company Z (PR1, PR2, PR3, PR4, PR6, PR7, PR9) in the Product Responsibility category.
6. Company X (SO2), Company Y (SO7) and Company Z (SO1, SO3, SO4, SO5, and SO6) in the Society category.

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Table 8. G3 Sustainability indicators values

	EC1	*EC2*	*EC3*	*EC4*	*EC5*	*EC6*	*EC7*	*EC8*
Comp. X	0.332	0.329	0.332	0.312	0.410	0.216	0.583	0.239
Comp. Y	0.353	0.274	0.313	0.312	0.243	0.090	0.138	0.184
Comp. Z	0.313	0.395	0.353	0.375	0.346	0.693	0.277	0.575
	EC9	***EN1***	***EN2***	***EN3***	***EN4***	***EN5***	***EN6***	***EN7***
Comp. X	0.445	0.647	0.349	0.281	0.369	0.373	0.259	0.367
Comp. Y	0.342	0.202	0.150	0.066	0.454	0.177	0.196	0.114
Comp. Z	0.212	0.150	0.499	0.652	0.175	0.448	0.544	0.517
	EN8	***EN9***	***EN10***	***EN11***	***EN12***	***EN13***	***EN14***	***EN15***
Comp. X	0.253	0.258	0.290	0.239	0.241	0.239	0.379	0.180
Comp. Y	0.206	0.258	0.090	0.199	0.201	0.184	0.165	0.078
Comp. Z	0.540	0.483	0.618	0.560	0.556	0.575	0.455	0.740
	EN16	***EN17***	***EN18***	***EN19***	***EN20***	***EN21***	***EN22***	***EN23***
Comp. X	0.440	0.360	0.254	0.347	0.352	0.377	0.303	0.379
Comp. Y	0.191	0.171	0.195	0.165	0.352	0.247	0.303	0.165
Comp. Z	0.367	0.468	0.549	0.486	0.294	0.374	0.393	0.455
	EN24	***EN25***	***EN26***	***EN27***	***EN28***	***EN29***	***EN30***	***HR1***
Comp. X	0.373	0.180	0.234	0.431	0.325	0.362	0.394	0.345
Comp. Y	0.177	0.078	0.190	0.226	0.154	0.151	0.484	0.164
Comp. Z	0.448	0.740	0.574	0.342	0.520	0.486	0.120	0.490
	HR2	***HR3***	***HR4***	***HR5***	***HR6***	***HR7***	***HR8***	***HR9***
Comp. X	0.299	0.259	0.241	0.264	0.472	0.360	0.375	0.242
Comp. Y	0.272	0.196	0.199	0.126	0.143	0.156	0.461	0.197
Comp. Z	0.428	0.544	0.559	0.609	0.384	0.483	0.162	0.560
	LA1	***LA2***	***LA3***	***LA4***	***LA5***	***LA6***	***LA7***	***LA8***
Comp. X	0.375	0.289	0.375	0.253	0.241	0.375	0.370	0.360
Comp. Y	0.162	0.320	0.163	0.206	0.199	0.161	0.173	0.112
Comp. Z	0.461	0.389	0.461	0.540	0.558	0.462	0.455	0.526
	LA9	***LA10***	***LA11***	***LA12***	***LA13***	***LA14***	***PR1***	***PR2***
Comp. X	0.334	0.240	0.242	0.257	0.260	0.350	0.259	0.241
Comp. Y	0.253	0.195	0.197	0.194	0.183	0.151	0.196	0.196
Comp. Z	0.411	0.563	0.560	0.547	0.555	0.497	0.544	0.561
	PR3	***PR4***	***PR5***	***PR6***	***PR7***	***PR8***	***PR9***	***SO1***
Comp. X	0.242	0.240	0.457	0.322	0.242	0.387	0.375	0.342
Comp. Y	0.197	0.202	0.285	0.244	0.197	0.462	0.162	0.160
Comp. Z	0.560	0.556	0.257	0.432	0.560	0.155	0.461	0.496
	SO2	***SO3***	***SO4***	***SO5***	***SO6***	***SO7***		
Comp. X	0.412	0.253	0.313	0.217	0.241	0.322		
Comp. Y	0.356	0.206	0.237	0.102	0.199	0.343		
Comp. Z	0.230	0.540	0.448	0.679	0.558	0.333		

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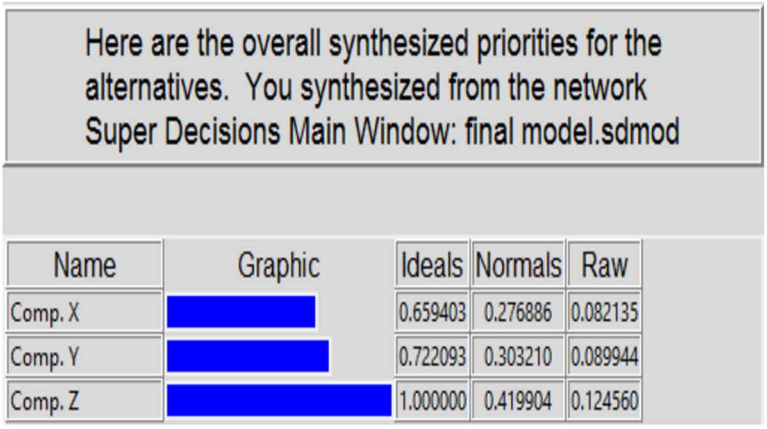
Figure 5. Synthesis results



Synthesis Results

Figure 5 shows the overall synthesized result of the ANP model, the Company Z shows the most sensitivity to the adoption of the indicators followed by Company Y and Company X.

The "Raw" column shows the priorities from limiting super matrix, the "Normals" column shows the normalized values for each component and the "Ideal" column shows the result by dividing the values in either columns by the largest value in that column.

Sensitivity Analyses

The sensitivity analyses in the super decisions software can be done under the computations tab. The sensitivity analyses of the three companies being pair wise compared is shown in Figure 6.

From the Figure 6 it can be noticed that Company Z has the highest value which is already being proved from the synthesis results from Figure 5.

Figure 7 shows the result of altering the value of the indicator C1. From the sensitivity analyses, 'Company Z' still remains dominant even if the value of C1 changes as it is strongly supported by the other indicators.

CONCLUSION

In the research, the sustainability advantages, challenges and different tools used by the business organizations to measure sustainability are examined. A hybrid approach integrating sustainability scorecard framework and ANP is proposed for measuring overall organizational sustainability. The proposed sustainability scorecard provides a strong framework for improvement as the indicators used are industry specific, strongly supported by the core values and integration with other indicators provides the flexibility to study the impact of one indicator over another. The ANP model helps to study the strength of the interactions and derive the priorities of indicators. All the stakeholders, decision makers are involved in the development of sustainability scorecard which provides an overall balance and completes

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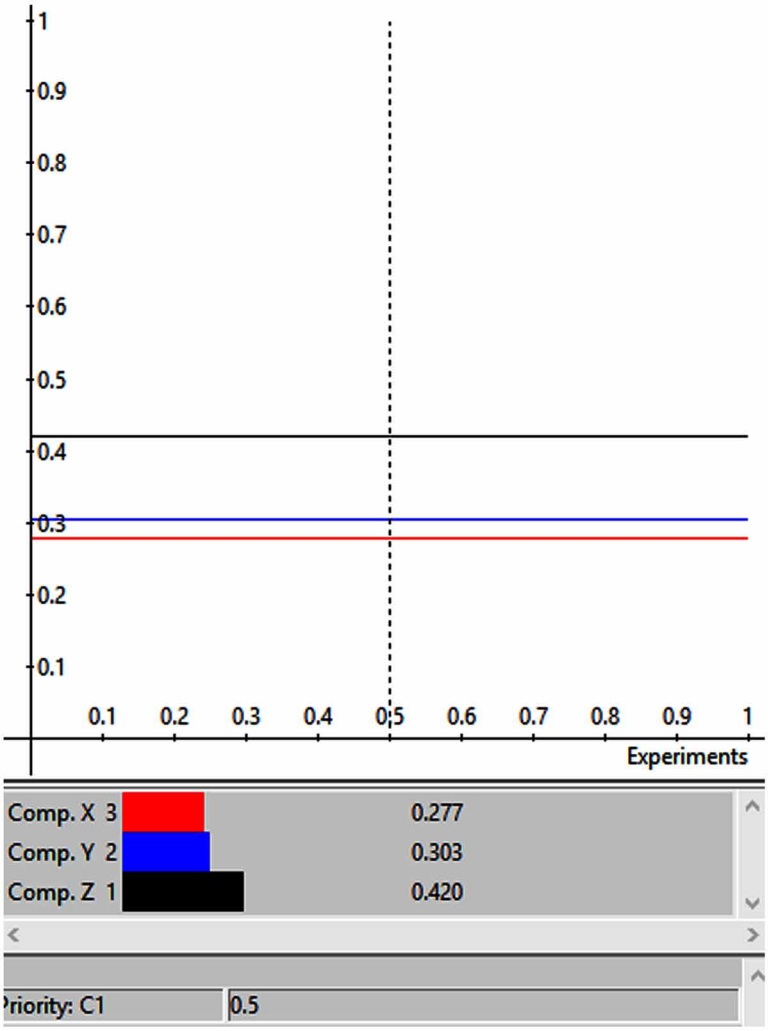
Figure 6. Sensitivity analysis 1



the model for mathematical analysis. Secondly, sustainability has been extensively studied using data collected from most sustainable companies. The key indicators in the sustainability scorecard have been analyzed for all set of companies' i.e. financial, health care, industrial, material etc. The presented data can be used as a benchmarking tool.

In the numerical analysis chapter, the application of the sustainability scorecard with the multi criteria decision making technique - Analytic Network Process (ANP) is presented. Pair wise comparisons of the indicators for three companies (X, Y and Z) are performed to analyze their performance against the other indicators. Sensitivity analyses has been presented.

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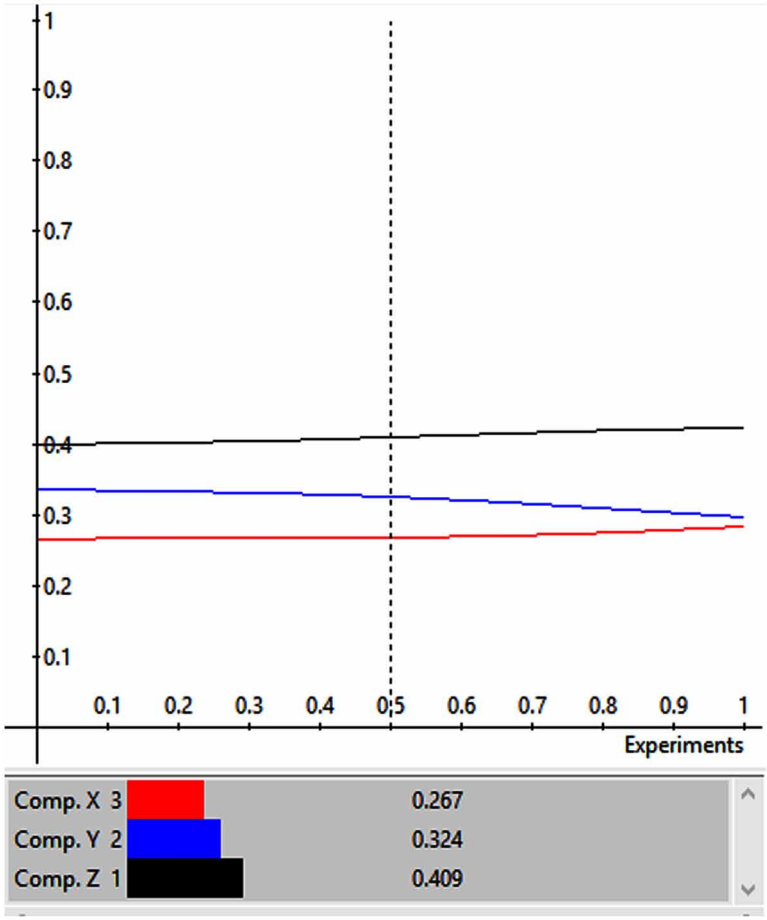
Figure 7. Sensitivity analysis 2



Limitations

1. The indicators used for GRI reporting are G3, more detailed version of the indicators have been published by GRI i.e. G4 guidelines.
2. Non-availability of G3 data for some companies in most sustainable companies list can result in deviation and may lead to wrong indicator selection.
3. The values used for pair wise comparisons in the numerical analysis chapter are non- real so the overall outcome is not guaranteed.

FUTURE WORK

In future, present work can be advanced by applying the sustainability scorecard to different industries, as the model works on the set of indicators, different businesses relies on different indicators and strategies for the performance measurement. Testing the model against distinct set of indicators and real data can give an insight to the sustainability scorecard adaptation in various sectors.

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Chapter 8
Modeling Barriers in Green Procurement using ISM:
A Comparison for Canadian and Iranian Automotive Industry

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ABSTRACT

Green procurement, a significant part of green supply chain management, plays a key role in implementing the green concept by considering the environmental issues. Due to increase in public awareness about environmental criteria, industries have been forced to consider environmental issues in their current production flows. Further, since the automotive industry has a direct impact on the environment, it is very beneficial to study the barriers that prevent this industry from implementing the green concept. Iran has had a considerable growth in the automotive industry in the last few decades and today owns and operates the largest automotive factory in the Middle East. In contrast, Canada as a leader in environmental issues does not have a large automotive industry, but is a country where some localized international companies have located small factories. The differences between these two countries make their comparison more valuable and noteworthy. This study investigates this comparison based on a structural modeling methodology known as interpretive structural modeling (ISM).

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INTRODUCTION

"Supply chain is a system of organizations, people, activities, information, and resources involved in moving a product or service from supplier to customer". Supply chain activities transform natural resources, raw materials, and components into a finished product that is delivered to the end customer (Awasthi & Grybowska, 2014). In sophisticated supply chain systems, used products may re-enter the supply chain at any point where residual value is recyclable. Supply chains link value chains (Nagurney & Anna, 2006).

The flow of material in supply chain management is one-way if the green approach is not considered. Without the green concept, the supply chain flow is from the material suppler to the end customer, however focusing on environmental issues causes a strategic change. This is achieved by recycling some of the used parts into the supply chain (Beamon, 1999). It is what can be assumed as the impact of a changing paradigm in supply chain management because of the green supply chain management concept. Furthermore, applying the green concept to the supply chain causes additional activities. For instance, in traditional supply chain management, transportation is recognized simply as forward distribution, while the green supply chain concept has the potential to include reverse logistics as one crucial step to achieving green results (Rodrigue et al., 2001).

Recently, intention and information about environmental issues have been raised in public and professional areas. Last century's industrial and manufacturing activities have had a negative impact; as a direct result of these industrial achievements the ecosystem has been substantially damaged, and both the environment and ecosystem have been sacrificed (Hussain et al., 2016).

On the other hand, consumption of natural resources must be carefully considered because it contributes to damage to the environment and climate change as well as global warming. Moreover, natural resources are recognized as mostly non-renewable, where high consumption puts future generations at a high risk of lack of energy resources. Today, people are more aware of the environmental situation and it makes supply chain management easier than before. Furthermore, in managing society's expectations, a new concern regarding the environment and climate has been raised (Strandberg, 2002) and the responsibility to minimize impacts on the environment as well as climate (Hart, 1995; Henriques & Sadorsky, 1999; Walker et al., 2008). This concern is not equal in all countries and societies. Based on different levels of industrial development, economic growth, social beliefs about the environment and the notion of nature, and finally public awareness, using the green approach will be different for each country.

It is noted that strict regulations, especially in developed countries, raise the need for new technologies that respect the environmental and green criteria. Therefore, supply chain management and procurement in particular has become more strategic and critical (Zhu et al., 2008). Although lowest price and highest quality are the main goals of procurement, including the green approach along with the other activities should surely be considered.

In purchasing, to achieve a better result in green supply chain management, it is necessary to consider efficiency along with technological demands, which are mostly equal everywhere and only the severity or significance of some issues makes a difference.

As Van Hoek and Erasmus (2000) and Rao and Holt, (2010) pointed out, "green supply chain management is an important organizational philosophy, (which) plays a significant role in promoting efficiency and synergy between partners, facilitating environmental performance, minimal waste, cost savings to achieve corporate profit and market-share objectives, through environmental risks and impacts reduction, while it improves the ecological efficiency of organizations and their partners". While performing any green supply chain management projects and specifically procurement, all barriers must be defined

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and then be eliminated if possible, and if they cannot be eliminated, they should be made as ineffective as possible.

The objective of this paper is to identify the various barriers that prevent the implementation of green procurement in the Iranian and Canadian automotive industries. Secondly, all possible correlations between the barriers will be investigated. Thirdly, based on ISM methodology, these barriers will be classified by their dependence power and driving power and lastly, the results for Iran and Canada will be compared.

The primary axiom in ISM indicates that considering only individual variables is not sufficient for the study of a phenomenon. To achieve highly accurate and comprehensive outcome, it is necessary to investigate interaction between these variables and consider the correlations among them.

LITERATURE REVIEW

Green Procurement Background in Green Supply Chain Management

"Procurement is the acquisition of goods, services or works from an external source. It is favorable that the goods, services or works are appropriate and that they are procured at the best possible cost to meet the needs of the purchaser in terms of quality and quantity, time, and location" (Weel & Van, 2010). The green supply chain includes green procurement, green manufacturing, green logistics and green distribution. All these activities have same aim: to decrease unwanted effects on the environment (Olugu et al., 2010). Procurement in green supply chain management consists of the traditional form of supply chain management activities along with the environmental concerns, which have been considered as part of organizational procurement decisions and long term transactions with suppliers (Gilbert, 2000).

One of the main objectives of green supply chain management is to decrease, or even eliminate, the waste of manufacturers in order to achieve more conservative energy consumption. Moreover, the prevention of harmful and hazardous materials dissolution into the environment and nature is beneficial. Implementation of industry 4.0 technologies such as robotics, internet of things, etc, can contribute to greening of the supply chain, and can result in increase in efficiency and productivity

Lamming & Hampson (1996), Beamon (1999), and Srivastava (2007) have discussed how a green approach in procurement as a key step of supply chain management is essential and significant; some of them examined implementation of green issues in this field.

Interpretive structural modeling (Warfield, 1974) as a deeply effective methodology has been pursued by too many researchers and investigators to model green supply chain management or its sub-issues. Martilla and James (1977) developed a driving and dependent power analysis to designate the degree of dependence and driving power of criteria. Huang et al (2005) proposed integrating ISM and an analytical network, and analyzed the interaction of criteria that was used to select the green suppliers, based on the environmental performance (Kannan et al., 2008). Mudgal et al. (2010) used ISM to model the enablers and barriers of green supply chain management in the Indian manufacturing industries. Vimal et al. (2011) applied ISM technique to study the adoption of renewable energy in India. Ming and Yuan (2011) developed an ISM-based model to manage municipal solid waste in Taipei. Luthra et al. (2011) utilized the ISM model to evaluate the barriers of green supply chain management in the automotive industry in India. Balasubramanian (2012) utilized ISM to build a hierarchical framework of barriers to green supply chain management in the construction sector. Mathiyazhagan et al. (2013) followed an ISM approach for the barrier analysis in implementing green supply chain management. Kumar et al.

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(2013) carried out an interpretive structural modeling on the deployment of customer involvement in green supply chain. Balaji et al. (2014) performed an investigation of barriers in green supply chain management from an Indian foundry perspective by performing an ISM analysis.

Green Procurement

As previously mentioned, green supply chain consists of green procurement, green manufacturing, green logistics and green distribution. All these activities are meant to decrease unwanted effects on the environment (Olugu et al., 2010). Although procurement can play a unique role when performing green supply chain management, the major challenge occurs when the purchaser tries to balance different criteria along with applying green goals in the traditional procurement process. Accordingly, it can be called managing a host of tradeoffs which include cost, quality and schedules with eco-efficiency between them. When a purchaser decides to place an order with a supplier, it is necessary to investigate many questions regarding all environmental issues related to this order. Some of them may have a direct impact on the environment, while others might have a delayed effect on nature and climate. Thus, preparing a comprehensive procurement plan which is capable of putting all elements and their effects under consideration is certainly essential. The plan can contribute green procurement methods in addition to maintaining the green criteria in suppliers.

All these plans and issues evolve into some critical drivers for the procurement process. Accordingly, green procurement should mostly be limited to these main drivers: risk reduction, cost efficiency, performance improvement and innovation of new product development. Each driver can impact individually the procurement process as well as product.

PROBLEM DESCRIPTION

Lately, many events and activities have increased public awareness about the destructive effects of current industrial activities on the environment and ecosystem (Kaur et al., 2018). As a result, end users of all manufacturers have a different perception about purchasing products and their actual need for them. At the present time, ordinary end users consider all environmental concerns along with their usual expectations about products and quality. However, there are differences in the level of interest over environmental concerns within different societies.

In Iran, for the last forty years and especially in last two decades, the automotive industry has been established and grown up dramatically. However, along with this development, the environment and nature have been sacrificed in various ways. Similar to other Asian countries, there was a lack of adequate attention regarding green concepts and environmental concerns in the development of the industry. At the present time, two major automotive groups lead the Iranian automotive industry and after years of delays, they are starting to implement green concept projects in their current activities.

Canada has a markedly different situation, and can be considered as one of the countries which has a comprehensive plan for green concept projects. The majority of the groups and manufacturers who operate in Canada put this issue in their targets. However, there are still some barriers to implement green concepts effectively.

With regard to the automotive industry in Canada, there is a particular obstacle. All of the automobile manufacturers in Canada are foreign international organizations and not Canadian. USA, Japan, Germany

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and Korea have based some of their production lines in Canada, creating a situation that can lead to threat as well as opportunity. Threat can occur when the foreign manufacturers are from countries that do not have a very well developed green approach in their production lines. On the other side, opportunity can occur when foreign manufacturers are from countries that are ecologically friendly and that consider all environmental concerns in their production lines.

Through research and other sources, many barriers could be considered for both countries. But as the result of more than 14 years of experience in this field and consulting with experts in the Iranian and Canadian automotive industry, the following barriers have been addressed for the two countries. For Iran, there are twenty barriers and for Canada there are fourteen. Although Iran and Canada are at different levels of interest and implementation of green concepts, according to former research and also investigations into the same industry, some of these issues are the same for both countries. This can give us a more accurate comparison at the end of our study for the two countries. Table 1 and 2 show the barriers in Iran and Canada respectively.

SOLUTION METHODOLOGY

In this study, the methodology of ISM is used to get results. ISM is a well-determined methodology for recognizing the relationships between particular items which describe a problem or an issue. This method has been used in various researches to reflect the interaction among various issues that are connected to one issue. The ISM process turns uncertain, weak detailed conceptual models for a system into obvious and clear models.

Interpretive Structural Modeling (ISM)

"ISM is defined as a process aimed at assisting the human being to better understand what he/she believes and to recognize clearly what he/she does not know. Its most essential function is organizational. The information added (by the process) is zero. The value added is structural. The ISM process transforms unclear, poorly articulated mental models of systems into visible and well-defined models" (Attri et al., 2013; Grzybowska et al., 2014).

ISM is a technique in which a set of elements, regardless of whether they are directly or indirectly correlated, are organized and structured into a general model that can clarify all aspects of a complex issue by well-designed graphics and explain the outcome (Attri et al.,2013). The steps to draw the tables and graphics using this method are explained in Figure 1.

As noted in the literature review, there have been many attempts by researchers to find the result of interactive elements' effects and since ISM is an effective technique, many researchers have tried to develop it to achieve a more useful method for further analysis. Some of the useful characteristics of ISM are listed below:

1. This methodology is viewed as the outcome of the groups used to make decisions on whether and how the various elements can be correlated.
2. This method is a model that has been built based on the relationships between elements. At the end, due to the overall effects of these elements on each other, it can be assumed that a unique result is issued.

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Table 1. Description of green procurement barriers in Iran automotive industry

Barriers	Researchers who addressed this issue
1. Lack of government support systems for green manufacturing and products	Greer and Bruno (1996); Scupola (2003); Hosseini (2007); Srivastva (2007); Hsu et al. (2008); Mudgal et al. (2009); Al Khidir and Zailani (2009); Mudgal et al. (2010); Luthra et al. (2011); Mathiyazhagan et al. (2013)
2. Cheap sources of underground energies which encourage their waste	Our contribution
3. Lack of belief in the environmental benefits	Freeman et al. (1992); Klassen and Whybark (1999); Christmann (2000); Rutherfoord et al. (2000); Gerrans et al. (2000); Thompson (2002); Yuksel (2008); Mathiyazhagan et al. (2013)
4. Lack of social regulations and laws to encourage green manufacturing and to limit the underground sources consumption	Ravi et al. (2005); Hsu et al. (2008); Mudgal et al. (2009); Luthra et al. (2011);Mathiyazhagan et al. (2013)
5. Limitation in entering new technology, process and materials	Perron (2005); Mathiyazhagan et al. (2013)
6. Insufficient IT implementation across the supply chain	Faruk et al. (2002); Ravi et al.(2005); Al Khidiret al. (2009); Luthra et al.(2011); Mathiyazhagan et al.(2013)
7. Lack of protecting green procurement programs by top management	Hillary (2000); Min and Galle(2001); Thompson (2002); Ravi and Shankar (2005); Zhu et al.(2007); Hsu and Hu (2008); Mudgalet al. (2009); Mudgal et al.(2010); Luthra et al.(2011); Mathiyazhagan et al.(2013)
8. Weak policy in organizations for inter-departmental collaboration to reach to green products	Tilley (1999); Ravi and Shankar (2005); Perron (2005); Yu (2007); Hsu et al.(2008); Luthra et al. (2011); Mathiyazhagan et al. (2013)
9. Lack of qualified human resources	Hillary (2000); Thompson (2002); Perron (2005); Yu (2007); Hsu et al. (2008); Luthra et al. (2011); Mathiyazhagan et al.(2013)
10. Insistence on accepting innovation and new technologies in suppliers	Hosseini (2007); Hsu et al. (2008); Al Khidir et al. (2009); Luthra et al. (2011)
11. Absence of appropriate and useful green measures in suppliers	Rao and Holt (2005); Mathiyazhagan et al. (2013)
12. Complex and costly purchase of products with capability to be reused or recycled	Mathiyazhagan et al. (2013)
13. Lack of sufficient realization and intention of end customers about green products	Roarty (1997); Barchard (1998); Tilley (1999); Hillary (2000); Bowen et al. (2001); Shen and Tam (2002); Orsato (2006); Chen et al., (2006); Mathiyazhagan et al.(2013)
14. Lack of training programs and advertisements to increase knowledge of end users in environmental measures	Roarty (1997); Bowen et al. (2001); Zhu and Sarkis (2004); Ravi et al. (2005);Orsato (2006); Chen et al. (2006); Zhu et al. (2007); Zhu et al. (2008); Mudgal et al. (2009); Mathiyazhagan et al. (2013)
15. Difficulty of maintaining and monitoring the environmental practice of suppliers	Wycherley (1999); Mudgal et al. (2010); Mathiyazhagan et al. (2013)
16. Lack of technical expertise in suppliers	Barchard (1998); Tilley (1999); Hillary (2000); Bowen et al. (2001); Shen and Tam (2002); Perron (2005); Mathiyazhagan et al.(2013)
17. Lack of reverse logistics system in suppliers to decrease the price	Ravi and Shankar (2005); Mathiyazhagan et al. (2013)
18. Financial and cost constraints	Barchard (1998); Wycherley (1999); Min and Galle (2001); Thompson (2002); Ravi et al. (2005); Ravi and Shankar (2005); Orsato (2006); Yu (2007); Hosseini (2007); Mudgal et al. (2009); Al Khidir and Zailani (2009); Mudgal et al. (2010); Luthra et al.(2011); Mathiyazhagan et al. (2013)
19. Need to high investments and less return-on-investments in short term	Mathiyazhagan et al. (2013)
20. Non-availability of loans and grants to encourage green products/processes	Mathiyazhagan et al. (2013)

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Table 2.

Barriers	Researchers who addressed this issue
1. Insufficient IT implementation across the supply chain	Faruk et al. (2002); Ravi et al. (2005); Al Khidiret al. (2009); Luthra et al. (2011); Mathiyazhagan et al. (2013)
2. Insufficient investment in recycling industries	Perron (2005)
3. Market competition	Rao and Holt (2005); Perron (2005); Hosseini (2007); Yu (2007); Mudgal et al. (2010); Mathiyazhagan et al. (2013)
4. Insufficient protecting of green procurement by top managements	Hillary (2000); Min and Galle (2001); Thompson (2002); Ravi and Shankar (2005); Hsu and Hu (2008); Mudgal et al. (2009); Mudgal et al.(2010); Luthra et al.(2011); Mathiyazhagan et al.(2013)
5. Lack of belief in inter-departments co-operation to make green products	Tilley (1999); Ravi and Shankar (2005); Perron (2005); Yu (2007); Hsu et al.(2008); Luthra et al. (2011); Mathiyazhagan et al.(2013)
6. Lack of qualified human resources	Hillary (2000); Thompson (2002); Perron (2005); Yu (2007); Hsu et al. (2008); Luthra et al. (2011); Mathiyazhagan et al. (2013)
7. Absence of appropriate and useful green measures in suppliers	Rao and Holt (2005); Mathiyazhagan et al.(2013)
8. Complex and costly purchase of products with capability to be reused or recycled	Mathiyazhagan et al. (2013)
9. Insufficient realization and intention of end customers about green products	Roarty (1997); Barchard (1998); Tilley (1999); Hillary (2000); Bowen et al. (2001); Shen and Tam (2002); Orsato (2006); Chen et al. (2006); Mathiyazhagan et al. (2013)
10. Difficulty of maintaining and monitoring the environmental practice of suppliers	Wycherley (1999); Mudgal et al. (2010); Mathiyazhagan et al. (2013)
11. Lack of technical expertise in suppliers	Barchard (1998); Tilley (1999); Hillary (2000); Bowen et al. (2001); Shen and Tam (2002); Perron (2005); Mathiyazhagan et al. (2013)
12. Lack of reverse logistic system in suppliers to decrease the price	Ravi and Shankar (2005); Mathiyazhagan et al. (2013)
13. Financial and cost constraints	Barchard (1998); Wycherley (1999);Min and Galle (2001); Thompson (2002); Ravi et al. (2005); Ravi and Shankar (2005); Orsato (2006); Hosseini (2007); Yu (2007); Hosseini (2007); Mudgal et al. (2009); Al Khidir and Zailani (2009); Mudgal et al. (2010); Luthra et al.(2011); Mathiyazhagan et al. (2013)
14. Need to high investments and less return-on-investments in short term	Mathiyazhagan et al. (2013)

3. It can be helpful to impose order and direction on the elaboration of relations between the different elements.

In spite of the benefits in using this methodology, there are a few disadvantages in using this technique. The contextual relationship between variables and elements is always designated and described based on the knowledge of users and their information about the subject. Therefore, in cases where the user is biased, it could affect the result of the study. Furthermore, some subjects may address many variables. Using ISM in these cases is complicated and sometimes it can be observed that results are mismatched. Hence, to utilize this methodology effectively, it is critical to pick only the significant items for this study.

Steps of ISM

The steps for using the ISM method are listed below:

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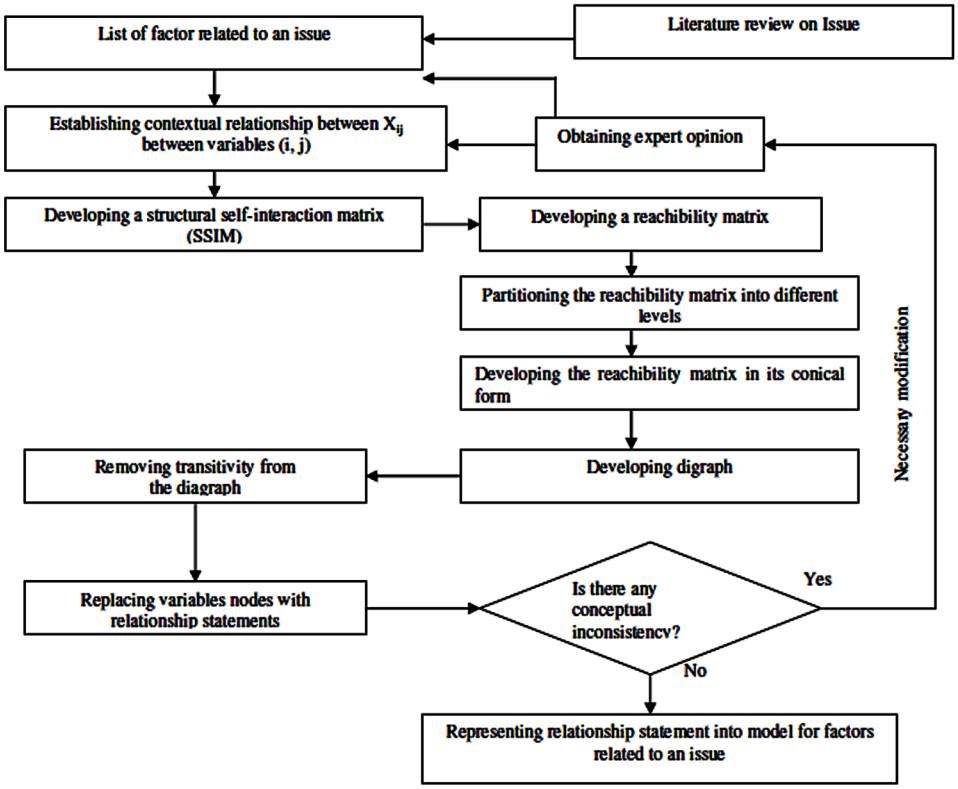
Figure 1. Flow diagram for preparing the ISM model (Attri et al., 2013)



Step 1: Identify the elements that are relevant to the problem.

Step 2: Establish a contextual relationship between the elements with respect to the pairs of elements which would be examined.

Step 3: Develop a structural self-interaction matrix (SSIM) of elements. This matrix indicates the pairwise relationship among elements of the system. This matrix is checked for transitivity.

Step 4: Develop a reachability matrix from the SSIM.

Step 5: Partition the reachability matrix into different levels.

Step 6: Convert the reachability matrix into conical form.

Step 7: Draw a diagram based on the relationship given in the reachability matrix and remove the transitive links.

Step 8: Convert the resultant diagram into an ISM-based model by replacing element nodes with the statements.

Step 9: Review the model to check for conceptual inconsistency and make the necessary modifications Attri et al., 2013).

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Gathering the Variables

According to current discussion, the barriers of implementing green procurement in the automotive industry have been extracted through general research for both countries. Consequently, the outcomes have been completed based on the knowledge and experience of experts in this field. These variables have been addressed and explained in Table 1 and Table 2.

(SSIM)-Self Interaction Matrix

According to the knowledge and experience of experts, the contextual relationships between the elements of both countries have been determined. Along with developing the SSIM, the following four symbols have been used to interpret the direction of the relationship between the two barriers *i* and *j*.

1. V- Barrier *i* will lead to barrier *j*;
2. A- Barrier *j* will lead to barrier *i*;
3. X- Barrier *i* and *j* will lead to each other;
4. O- Barrier *i* and *j* are unrelated

According to these contextual relationships, SSIM for both countries has been defined in Table 3 and Table 4. For instance in Table 3, variable 10 leads to variable 17, therefore symbol 'V' has been entered in the cell (10, 17); variable 19 leads to variable 4, therefore symbol 'A' has been entered in the cell (4, 19); variables 1 and 10 lead to each other, so symbol 'X' has been entered in the cell (1, 10); variables 2 and 12 do not lead to each other, so symbol 'O' has been entered in the cell (2, 12), and so on. The number of pairwise comparison questions addressed for developing the SSIM are $((N) \times (N-1)/2)$, where N is the number of variables.

Initial Reachability Matrix

The next step in the ISM method is to construct an initial reachability matrix from every SSIM that we have. To run, SSIM is transformed into the initial reachability matrix by replacing the four symbols (i.e., V, A, X or O) of SSIM by 1 or 0 in SSIM.

The rules for this replacement are as follows:

1. If the (i, j) entry in the SSIM was V, then the (i, j) entry in the reachability matrix would be 1 and the (j, i) entry 0.
2. If the (i, j) entry in the SSIM was A, then the (i, j) entry in the matrix would be 0 and the (j, i) entry 1 as well.
3. If the (i, j) entry in the SSIM was X, then the (i, j) entry in the matrix would be 1 and the (j, i) entry 1 as well.
4. If the (i, j) entry in the SSIM was O, then the (i, j) entry in the matrix would be 0 and the (j, i) entry 0 as well.

Based on these rules, the initial reachability matrixes have been constructed in Tables 5 and 6.

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Final Reachability Matrix

After preparing the initial reachability matrix, in order to construct the final reachability matrixes, it is necessary to check those matrixes for transitivity. The transitivity of the contextual relationship means, if for instance variable A is related to variable B, and variable B is also related to variable C, then variable A necessarily is related to C (Luthra et al., 2011).

To determine the transitivity, it is necessary to check in the diagram of node and linking patch. That means if node A is linked to node B and node B is linked to node C, if node A is linked to node C, then we can declare it to be a transitive relation. Through the application of transitivity, the final reachability matrixes are obtained (Table 7, Table 8). In these matrixes, those cells which have been changed by applying transitivity are shown by 1*.

From the final reachability matrix, for each factor, reachability and antecedent sets can be selected. The reachability set includes the factor itself and the other factors that it may impact, while the antecedent set consists of the factor itself and the other factors that may impact it. Thus, the intersection of these sets is obtained for all the factors and consequently the levels of different factors are defined. In this process, the factors that the reachability and the intersection sets have the same values are located in the first level of ISM hierarchy. The first level factors are factors that won't lead the other factors above their own level in the hierarchy.

Immediately after identifying the first level factors, they should be removed from other factors. Then, this process will continue to reveal factors in the next levels up to the last level. (Warfield, 1974)

Formation of the ISM Based Model

Based on the reachability matrix, by using the nodes and linking lines, a preliminary diagram can be obtained (Figure 2 and Figure 3). This diagram is a visual representation of interdependence among the elements. This diagram can then be easily transformed to the ISM model by adding the statement into nodes (Attri et al., 2013).

MICMAC Analysis

Matriced' Impact scroises-Multipication Applique' and Classment (cross-impact matrix multiplication applied to classification) is abbreviated as MICMAC. The MICMAC origin is according to multiplication properties of matrixes. MICMAC allows us to understand and analyze the driving and dependence power of barriers. It helps us to verify the barriers from different viewpoints, and finally due to these specifications, the barriers can be categorized into four different classes as below:

1. Autonomous barriers: These barriers have weak driving power and weak dependence. They are disconnected from the system.
2. Dependent barriers: This category includes those barriers that have weak driving power but strong dependence power.
3. Linkage barriers: These have strong driving power as well as strong dependence. They do not have a stable situation and any changes to them can cause an impact on the other barriers, and then have a feedback effect on them.
4. Independent barriers: These barriers have strong driving power but weak dependence power.

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Table 3. Structural self-interaction matrix for barriers to implement green procurement in Iran automobile industry

	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2
1	V	O	V	V	O	O	V	V	O	O	X	O	O	V	O	V	V	X	X
2	X	V	V	O	O	O	V	V	O	O	O	O	O	O	O	O	V	V	
3	V	O	O	V	O	O	X	X	O	A	V	A	O	V	O	O	V		
4	V	A	V	V	V	O	V	V	X	O	O	A	O	X	A	O			
5	A	A	A	V	X	V	O	O	V	O	A	A	O	A	V				
6	A	A	A	V	A	V	V	V	O	V	O	A	V	V					
7	A	A	A	X	V	V	A	A	A	V	X	V	V						
8	O	O	O	O	A	V	A	O	O	O	V	A							
9	O	O	A	V	V	V	A	A	V	O	V								
10	A	A	A	V	A	V	A	A	A	O									
11	O	O	O	V	A	V	A	A	O										
12	A	A	A	A	A	O	A	O											
13	O	O	A	A	O	O	A												
14	O	A	A	V	V	V													
15	O	O	A	A	A														
16	O	O	A	V															
17	A	A	A																
18	A	A																	
19	A																		

Table 4. Structural self-interaction matrix for barriers to implement green procurement in Canada automobile industry

	14	13	12	11	10	9	8	7	6	5	4	3	2
1	A	A	V	A	V	V	O	V	A	V	V	V	O
2	A	A	V	V	O	V	A	O	O	O	A	A	
3	A	X	A	A	O	A	A	O	O	O	V		
4	A	A	X	V	V	A	A	V	V	V			
5	O	O	O	A	V	O	O	O	A				
6	O	A	V	V	V	A	V	O					
7	O	O	V	A	V	A	O						
8	A	A	A	A	O	O							
9	O	A	A	O	O								
10	O	A	A	A									
11	O	A	V										
12	A	A											
13	A												

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Table 5. Initial reachability matrix for barriers to implement green procurement in Iran automobile industry

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	0	1	1	1	1	1	0	1	1	0	1	1	1	0	1	1	1	1	1
2	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0	0	1	1	1	1
3	1	0	1	1	1	0	0	1	0	0	1	0	1	1	1	0	1	0	0	1
4	0	0	1	1	0	0	0	0	0	0	1	1	1	1	0	1	1	0	0	1
5	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	1	1	0	0	0
6	0	0	1	0	0	1	1	1	0	1	1	0	1	0	1	1	1	0	0	0
7	0	0	0	0	1	0	1	1	1	1	1	0	0	0	1	1	1	0	0	0
8	0	0	0	0	0	1	1	1	0	1	1	1	0	0	1	0	0	0	0	0
9	0	0	0	0	0	1	0	1	1	1	1	1	0	0	1	1	0	0	0	0
10	0	0	0	0	1	0	1	0	0	1	1	0	0	0	1	1	1	0	0	0
11	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	1	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
13	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0
14	0	0	0	1	0	0	1	1	0	0	1	1	1	1	1	0	1	1	0	0
15	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0
16	0	0	0	0	1	1	0	0	1	1	1	1	0	0	1	1	1	0	0	0
17	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0
18	0	0	1	0	1	1	0	0	1	1	0	1	0	0	0	0	1	1	0	0
19	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
20	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1

In our study these diagrams have been constructed and illustrated in Figure 4 and Figure 5.

RESULTS AND DISCUSSION

The automotive industry has grown up rapidly in Iran. Despite some new plans to maintain the quality of the environment, this industry is suffering from poor attention to the green concept. In contrast, in Canada, concern about the environment is not a new issue and there is strong focus to go further and faster in this field.

The result based on Figure 4 for Iran leads us to categorize Iranian barriers as below:

1. **Autonomous Barriers:** In this area, there is only barrier no. 19. Although it is placed on the boundary with the Driver area, it can be marginally considered within this class. This barrier is "need to high investments and less return-on-investments in the short term". As we know, since autonomous barriers have weak driving power and dependence, they are not able to affect the system. Furthermore, since there is just one barrier on the border of this area, it demonstrates our selected barriers mostly could play a key role.

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Table 6. Initial reachability matrix for barriers to implement green procurement in Canada automobile industry

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1	0	1	1	1	0	1	0	1	1	0	1	0	0
2	0	1	0	0	0	0	0	0	1	0	1	1	0	0
3	0	1	1	1	0	0	0	0	0	0	0	0	1	0
4	0	1	0	1	1	1	1	0	0	1	1	1	0	0
5	0	0	0	0	1	0	0	0	0	1	0	0	0	0
6	1	0	0	0	1	1	0	1	0	1	1	1	0	0
7	0	0	0	0	0	0	1	0	0	1	0	1	0	0
8	0	1	1	1	0	0	0	1	0	0	0	0	0	0
9	0	0	1	1	0	1	1	0	1	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	1	0	0	0	0
11	1	0	1	0	1	0	1	1	0	1	1	1	0	0
12	0	0	1	1	0	0	0	1	1	1	0	1	0	0
13	1	1	1	1	0	1	0	1	1	1	1	1	1	0
14	1	1	1	1	0	0	0	1	0	0	0	1	1	1

2. **Dependent Barriers**: In this class, there is barrier no. 12. In addition, barriers no. 11 and 15 can be considered fifty percent in this area. Therefore, "complex and costly purchase of products with capability to be reused or recycled" is a dependent barrier which has a very high dependence, but low driving power. Also, "absence of appropriate and useful green measures in suppliers" and "difficulty of maintaining and monitoring the environmental practice of suppliers", both have strong dependence and their driving power is in middle range. It means barriers related to the supplier issue can play a significant role because of their strong dependence by affecting other barriers. Furthermore, the mentioned barriers clarify that supplier measures and their monitoring require more consideration in the green concept.
3. **Linkage Barriers***:* The largest numbers of barriers are located here; being barriers no. 1, 13, 8, 3, 9, 7, 10, 16, 6, 18, 5, and 17. These barriers consist of:"lack of government support systems to support green manufacturing and products", "lack of sufficient realization and intention of end customers about green products", "weak policy in organizations for inter-departmental collaborations to reach to green products", "lack of belief in the environmental benefits", "lack of qualified human resources", "lack of protecting green procurement programs by top management", "insistence on accepting innovation and new technologies in suppliers", "lack of technical expertise in suppliers", "insufficient IT implementation across the supply chain", "financial and cost constraints", "limitation in entering new technology, process and materials " and "lack of reverse logistics system in suppliers to decrease the price".

With regard to this situation, it is obvious that there are many barriers which play a vital role in this study. However, "financial and cost constraints", "limitation in entering new technology, process and

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Table 7. Final reachability matrix for barriers to implement green procurement in Iran automobile industry

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Driving Power
1	1	0	1	1	1	1	1	1*	1	1	1*	1	1	1	1*	1	1	1	1	1	19
2	1	1	1	1	1	1*	1*	1*	1*	1	1	1	1	1	1*	1*	1	1	1	1	20
3	1	0	1	1	1	1*	1*	1	1*	1*	1	1*	1	1	1	1*	1	1*	1*	1	19
4	1*	0	1	1	1*	1*	1*	1*	1*	1*	1	1	1	1	1*	1	1	1*	1*	1	19
5	0	0	1*	0	1	1	1*	1*	1*	1*	1*	1	1*	0	1*	1	1	0	0	0	13
6	1*	0	1	1*	1*	1	1	1	1*	1	1	1*	1	1*	1	1	1	1*	0	1*	18
7	1*	0	0	0	1	1*	1	1	1	1	1	1*	0	0	1	1	1	1*	0	0	13
8	0	0	1*	0	1*	1	1	1	1*	1	1	1	1*	0	1	1*	1*	1*	0	0	14
9	0	0	1*	0	1*	1	1*	1	1	1	1	1	1*	0	1	1	1*	1*	0	0	14
10	1*	0	0	0	1	1*	1	1*	1*	1	1	1*	0	0	1	1	1	1*	0	0	13
11	1*	0	0	0	1*	0	1*	0	0	1	1	1*	0	0	1	1*	1	1*	0	0	10
12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
13	1*	0	1	1	1*	1*	1*	1*	1*	1*	1*	1*	1	1*	1*	1*	1	1	0	1*	18
14	1*	0	1*	1	1*	1*	1	1	1*	1*	1	1	1	1	1	1*	1	1	0	1*	18
15	0	0	1*	0	1*	1*	0	0	1*	1*	1	1*	0	0	1	0	1*	1	0	0	10
16	1*	0	1*	0	1	1	1*	1*	1	1	1	1	1*	0	1	1	1	1*	0	0	15
17	1	0	1*	1*	1*	1*	1	1*	1*	1*	1*	1	1*	1*	1*	1*	1	1*	1*	1*	19
18	1*	0	1	1*	1	1	1*	1*	1	1	1*	1	1*	1*	1*	1*	1	1	0	1*	18
19	1*	0	1*	0	1	1*	1*	0	0	0	0	1*	0	0	0	1*	1*	1	1	0	10
20	0	0	1*	0	1	1	1*	1*	1*	1*	1*	1*	1*	0	1*	1*	1*	1	1	1	16
Dependence Power	14	1	16	9	19	18	18	16	17	18	18	20	14	9	18	18	19	18	7	10	

materials" and "lack of reverse logistics system in suppliers to decrease the price", have the most significant impact among all the other barriers because of their high dependence and high driving power.

For the "limitation in entering new technology, process and materials", there are various reasons but the fundamental reason is simply because of Iran's particular situation in the world markets. In fact, Iran in recent years has been surrounded by sanctions that limit its access to world markets. Therefore, access to new processes, technologies or materials has been restricted, even if the top managers desired it. Furthermore, the Iranian automotive industry and market are traditionally controlled by government. Hence, this industry and market suffers from the lack of beneficial communication with other countries. This is the primary reason that the automotive industry cannot be influenced by the green industries of developed countries. Furthermore, "financial and cost constraints" is another vital barrier. Actually the meaning of competition is a bit different in this area. In Iran, price is mostly considered as the main criteria in competition, while in developed and green societies, environmental issues are the most significant constraint in their industries. In Iran, the government plays a vital role in the automotive market

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Table 8. Final reachability matrix for barriers to implement green procurement in Canada automobile industry

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Driving Power
1	1	1*	1	1	1	1*	1	0	1	1	1*	1	1*	0	12
2	1*	1	1*	1*	1*	1*	1*	1*	1	1*	1	1	0	0	12
3	0	1	1	1	1*	1*	1*	0	1*	1*	1*	1*	1	0	11
4	1*	1	1*	1	1	1	1	1*	1*	1	1	1	0	0	12
5	0	0	0	0	1	0	0	0	0	1	0	0	0	0	2
6	1	1*	1*	1*	1	1	1*	1	1*	1	1	1	0	0	12
7	0	0	1*	1*	0	0	1	1*	1*	1	0	1	0	0	7
8	0	1	1	1	1*	1*	1*	1	1*	0	1*	1*	1*	0	11
9	1*	1*	1	1	1*	1	1	1*	1	1*	1*	1*	1	0	13
10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
11	1	1*	1	1*	1	0	1	1	1*	1	1	1	1*	0	12
12	0	1*	1	1	1*	1*	1*	1	1	1	0	1	1*	0	11
13	1	1	1	1	1*	1	1*	1	1	1	1	1	1	0	13
14	1	1	1	1	1*	1*	1*	1	1*	1*	1*	1	1	1	14
Dependence Power	8	11	12	12	12	10	12	10	12	13	10	12	8	1	

because they control the market, so the final price is fixed, as it always has been. Furthermore, the Iranian government has not mandated making green measures the automotive industry's obligation. Therefore, every green activity must be considered an extra expense in the Iranian environment.

Finally, the "lack of reverse logistics system in suppliers to decrease the price" has become the most significant barrier. It is clear that fundamentally, the Iranian automotive industry does not have a complete and true understanding about the effectiveness of this system yet.

1. **Independent Barriers***:* Barriers no. 2, 14, 4 are entered in this category. Also barrier no. 20 is placed on the border with the linkage area. These barriers are: "cheap sources of underground energies which encourage their waste", "lack of training programs and advertisements to increase knowledge of end users in environmental measures", "lack of social regulations and laws to encourage green manufacturing and to limit the underground source consumption" and "non-availability of loans and grants to encourage green products/processes". These barriers and particularly "cheap sources of underground energies which encourage their waste" have a high level of driving power but do not affect other barriers. Thus, the aforementioned barriers that have the highest amount of driving power need closer consideration for solving the green barriers problems.

The Canadian automotive industry barriers for implementing green procurement are classified based on Figure 4 as below:

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Table 9. Level partitions for barriers to implement green procurement in Iran automobile industry

Barriers	Reachability set	Antecedent set	Intersection set	Iteration no. & level
1	1,3,4,5,6,7,8,9,10,11,12,13,14,15,16, 17,18,19,20	1,2,3,4,6,7,10,11,13,14,16,17,18,19	1,3,4,6,7,10,11,13,14,16,17,18,19	**V**
2	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16 ,17,18, 19,20	2	2	**VI**
3	1,3,4,5,6,7,8,9,10,11,12,13,14,15,16, 17,18,19,20	1,2,3,4,5,6,8,9,13,14,15,16,17,18,1 9,20	1,3,4,5,6,8,9,13,14,15,16,17,18, 19,20	**III**
4	1,3,4,5,6,7,8,9,10,11,12,13,14,15,16, 17,18,19,20	1,2,3,4,6,13,14,17,18	1,3,4,6,13,14,17,18	**V**
5	3,5,6,7,8,9,10,11,12,13,15,16,17	1,2,3,4,5,6,7,8,9,10,11,13,14,15,16,1 7,18,19, 20	3,5,6,7,8,9,10,11,13,15,16,17	**II**
6	1,3,4,5,6,7,8,9,10,11,12,13,14,15,16, 17,18,20	1,2,3,4,5,6,7,8,9,10,13,14,15,16,17, 18,19,20	1,3,4,5,6,7,8,9,10,13,14,15,16,1 7,18,20	**III**
7	1,5,6,7,8,9,10,11,12,15,16,17,18	1,2,3,4,5,6,7,8,9,10,11,13,14,16,17, 18,19,20	1,5,6,7,8,9,10,11,16,17,18	**III**
8	3,5,6,7,8,9,10,11,12,13,15,16,17,18	1,2,3,4,5,6,7,8,9,10,13,14,16,17,18,20	3,5,6,7,8,9,10,13,16,17,18	**III**
9	3,5,6,7,8,9,10,11,12,13,15,16,17,18	1,2,3,4,5,6,7,8,9,10,13,14,15,16,17 ,18,20	3,5,6,7,8,9,10,13,15,16,17,18	**III**
10	1,5,6,7,8,9,10,11,12,15,16,17,18	1,2,3,4,5,6,7,8,9,10,11,13,14,15,16, 17,18,20	1,5,6,7,8,9,10,11,15,16,17,18	**II**
11	1,5,7,10,11,12,15,16,17,18	1,2,3,4,5,6,7,8,9,10,11,13,14,15,16, 17,18,20	1,5,7,10,11,15,16,17,18	**II**
12	12	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,1 6,17,18,19,20	12	**I**
13	1,3,4,5,6,7,8,9,10,11,12,13,14,15,16, 17,18,20	1,2,3,4,5,6,8,9,13,14,16,17,18,20	1,3,4,5,6,8,9,13,14,16,17,18,20	**V**
14	1,3,4,5,6,7,8,9,10,11,12,13,14,15,16, 17,18,20	1,2,3,4,6,13,14,17,18	1,3,4,6,13,14,17,18	**V**
15	3,5,6,9,10,11,12,15,17,18	1,2,3,4,5,6,7,8,9,10,11,13,14,15,16, 17,19,20	3,5,6,9,10,11,15,17	**IV**
16	1,3,5,6,7,8,9,10,11,12,13,15,16,17,18	1,2,3,4,5,6,7,8,9,10,11,13,14,16,17, 18,19,20	1,3,5,6,7,8,9,10,11,13,17,18	**III**
17	1,3,4,5,6,7,8,9,10,11,12,13,14,15,16, 17,18,19,20	1,2,3,4,5,6,7,8,9,10,11,13,14,15,16,1 7,18,19, 20	1,3,4,5,6,7,8,9,10,11,13,14,15,16, 17,18, 19,20	**II**
18	1,3,4,5,6,7,8,9,10,11,12,13,14,15,16, 17,18,20	1,2,3,4,6,7,8,9,10,11,13,14,15,16,17 ,18,19,20	1,3,4,6,7,8,9,10,11,13,14,15,16,1 7,18, 20	**III**
19	1,3,5,6,7,12,16,17,18,19	1,2,3,4,17,19,20	1,3,17,19	**IV**
20	3,5,6,7,8,9,10,11,12,13,15,16,17,18 ,19,20	1,2,3,4,6,13,14,17,18,20	3,6,13,17,18,20	**IV**

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Table 10. Level partitions for barriers to implement green procurement in Canada automobile industry

Barriers	Reachability set	Antecedent set	Intersection set	Iteration no. & level
1	1,2,3,4,5,6,7,9,10,11,12,13	1,2,4,6,9,11,13,14	1,2,4,6,9,11,13	**V**
2	1,2,3,4,5,6,7,8,9,10,11,12	1,2,3,4,6,8,9,11,12,13,14	1,2,3,4,6,8,9,11,12	**IV**
3	2,3,4,5,6,7,9,10,11,12,13	1,2,3,4,6,7,8,9,11,12,13,14	2,3,4,6,7,9,11,12,13	**V**
4	1,2,3,4,5,6,7,8,9,10,11,12	1,2,3,4,6,7,8,9,11,12,13,14	1,2,3,4,6,7,8,9,11,12	**IV**
5	5,10	1,2,3,4,5,6,8,9,11,12,13,14	5	**II**
6	1,2,3,4,5,6,7,8,9,10,11,12	1,2,3,4,6,8,9,12,13,14	1,2,3,4,6,8,9,12	**V**
7	3,4,7,8,9,10.12	1,2,3,4,6,7,8,9,11,12,13,14	3,4,7,8,9,12	**II**
8	2,3,4,5,6,7,8,9,11,12,13	2,4,6,7,8,9,11,12,13,14	2,4,6,7,8,9,11,12,13	**IV**
9	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,6,7,8,9,11,12,13,14	1,2,3,4,6,7,8,9,11,12,13	**IV**
10	10	1,2,3,4,5,6,7,9,10,11,12,13,14	10	**I**
11	1,2,3,4,5,7,8,9,10,11,12,13	1,2,3,4,6,8,9,11,13,14	1,2,3,4,8,9,11,13	**IV**
12	2,3,4,5,6,7,8,9,10,12,13	1,2,3,4,6,7,8,9,11,12,13,14	2,3,4,6,7,8,9,12,13	**III**
13	1,2,3,4,5,6,7,8,9,10,11,12,13	1,3,8,9,11,12,13,14	1,3,8,9,11,12,13	**V**
14	1,2,3,4,5,6,7,8,9,10,11,12,13,14	14	14	**VI**

Figure 2. Nodes and arrows for constructing ISM model of barriers for implementing green procurement in Iran

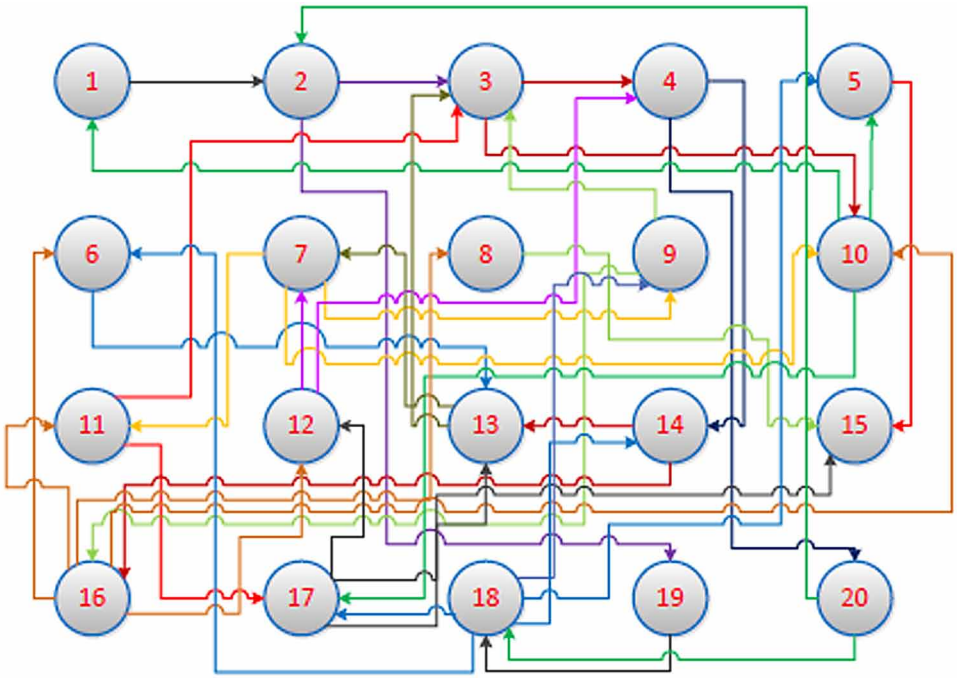

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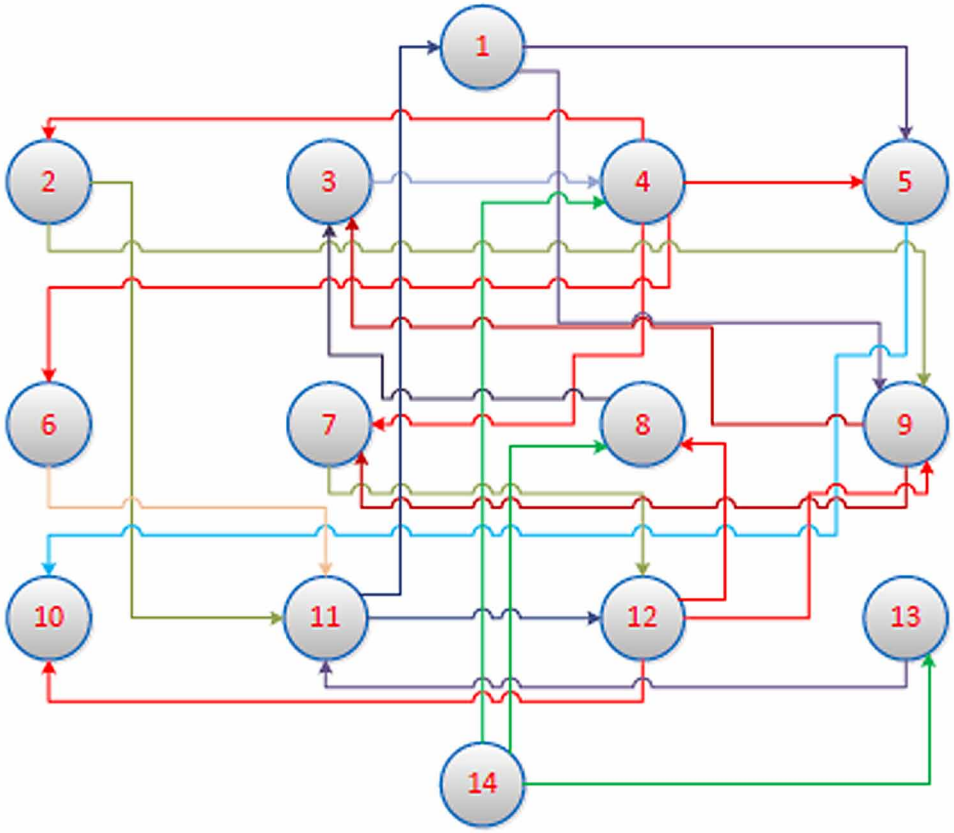
Figure 3. Nodes and arrows for constructing ISM model of barriers for implementing green procurement in Canada



1. **Autonomous Barriers**: In this area there is no barrier. This illustrates that the results of the study of Canada's automotive industry barriers for implementing green procurement are slightly better than Iran's. In fact, it means all barriers have an impact on each other, although the rate of influence is different.
2. **Dependent Barriers:** Barriers no. 5, 10 are placed in this area. Moreover, barrier 7 is on the border with linkage area. These barriers consist of "lack of belief in inter-departments co-operation to make green products", "difficulty of maintaining and monitoring the environmental practice of suppliers" and "absence of appropriate and useful green measures in suppliers". Although these barriers do not have a high driving power, they do have considerable dependency; therefore, they are capable of affecting other barriers.
3. **Linkage Barriers***:* A high number of barriers are observed in this area. These are barriers no. 1, 13, 8, 6, 11, 2, 3, 12, 4 and 9 which are "insufficient IT implementation across the supply chain", "financial and cost constraints", "complex and costly purchase of products with capability to be reused or recycled", "lack of qualified human resources", "lack of technical expertise in suppliers", "insufficient investment in recycling industries", "market competition", "lack of a reverse logistic system in suppliers to decrease the price", "insufficient protection of green procurement by top

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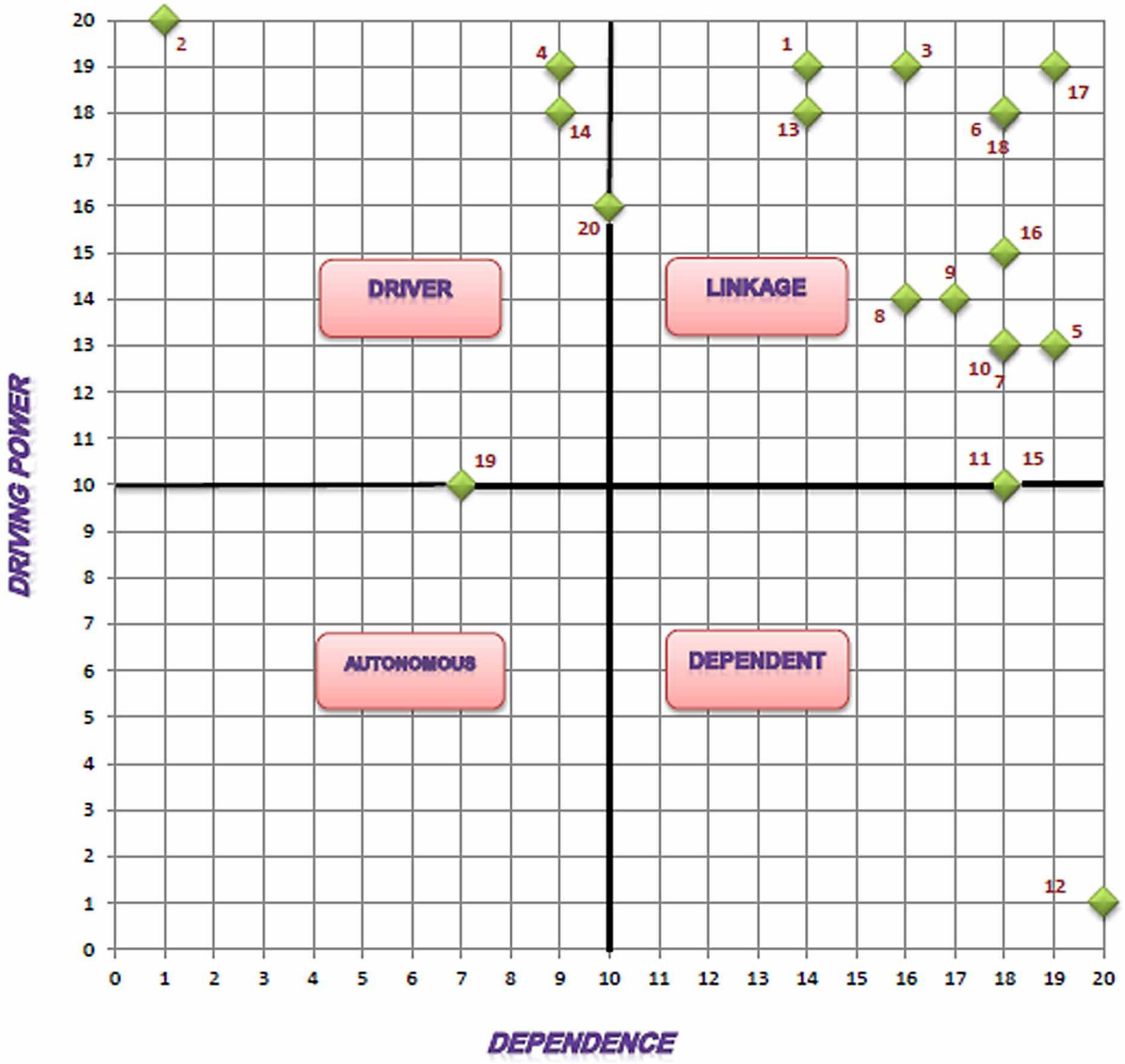
Figure 4. Cluster of barriers to implement green procurement in Iran automobile industry



managements" and "insufficient realization and intention of end customers about green products". All of these barriers are considerable, but the last two barriers appear to be of vital importance. They can be interpreted to mean the beliefs of top management and ordinary people as end consumers need to be closely examined and addressed in order to convince them to accept green practice as a matter of course.

4. **Independent Barriers:** Barrier no. 14 is the only barrier in this area. In fact "need to high investments and less return-on-investments in short term" has low dependence despite having a high level of driving power.

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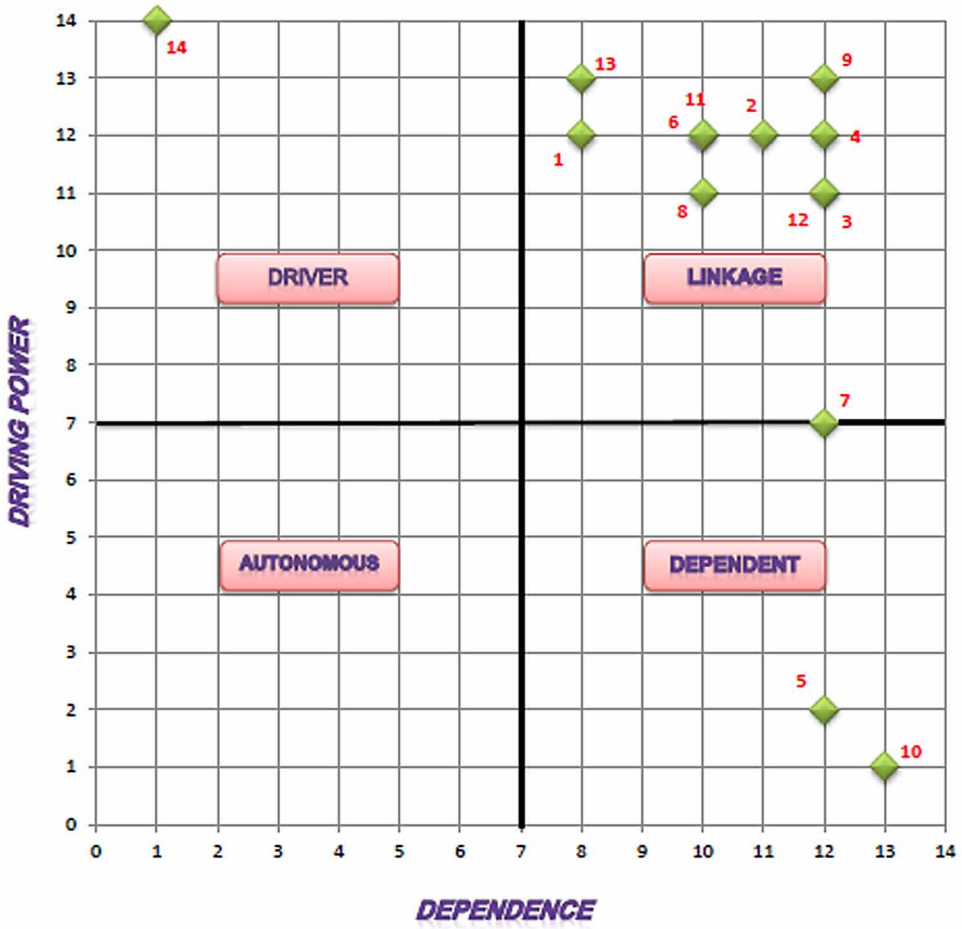
Figure 5. Cluster of barriers to implement green procurement in Canada automobile industry



CONCLUSION

Recently, the green concept has been highlighted progressively. Various societies chose different policies to manage all their environmental problems caused by industrial and other activities of mankind; however, this topic has reached a very important level in governmental and personal agendas.

By utilizing the ISM model, this study shows how different barriers play different roles in two different countries that want to perform procurement with a green background.

For Iran there were 3 significant barriers. “financial and cost constraints”, “limitation in entering new technology, process and materials” and “lack of a reverse logistics system in suppliers to decrease the price”. Although these barriers have a high dependency and they are highly influenced by other barriers, they have a high rate of driving power, which means that it is critical for them to be more focused.

Fortunately, two of these three barriers can be resolved following the easing of the Iran sanction situation if the Iranian government puts more supporting plans in place for green programs. Afterward, new technologies and processes will be more easily available from developed countries and moreover, the Iranian government will have more access to financial resources. As a result, it will help to convince

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the suppliers to become equipped for reverse logistics systems on their own initiative, in addition to a mandated government obligation, and to support them to prepare enough sources of information to show how this system can create new values and benefits. In the preliminary steps, it would be beneficial to give grants to firms that are candidates for establishing an efficient reverse logistic system.

Canada's study illustrated that the "insufficient protecting of green procurement by top managements" and "insufficient realization and intention of end customers about green products" were the most significant barriers, with high driving power and dependency as well. In fact, both barriers appear to be more social than otherwise. These kinds of barrier look easy to overcome at first glance, but in actuality, it is a time consuming job to change people's mind regarding the environment and the green concept, and to make top managers more interested in green concepts by providing additional information. The use of TV programs and celebrities could be useful for changing the general public's minds towards the green concept. For the management group, as they necessarily need more senior business programs, high-level training would be called for.

At the end of this study, it is important to point out that implementing ISM for the issues, including the many variables, as was done in this study, can lead to very complicated results. There are some ways to avoid this complexity, such as working to classify the barriers to more general issues, and decreasing the quantity of variables by omitting some unnecessary issues. However, schematically this technique could lead to uncovering some very beneficial ideas to resolving the barriers in two different societies.

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Chapter 9
European Union Emissions Trading Scheme: Design Evolution and Effectiveness Analysis

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ABSTRACT

The European Union Emissions Trading Scheme (EU-ETS), launched in 2005, is one of the most important market-driven initiatives in support to the global commitment to fight the climate changes and foster sustainable development. The scheme design evolution, comprising four phases, was characterized by continued ineffectiveness in driving emissions reduction, mainly for industries outside the power generation sector. This chapter brings an analysis of the EU-ETS design evolution, aiming at providing an overview on how the EU-ETS design features improvements impacted its effectiveness. The emissions trading scheme's main design features are listed, followed by the description of the EU-ETS design evolution in terms of scope, allowances allocation process, and emissions cap (among others). The greenhouse gases emissions trends, the carbon price behavior, and the availability of allowances in the EU carbon market are presented and discussed as key factors in support to the EU-ETS effectiveness assessment.

INTRODUCTION

Environmentally sustainable development was globally recognized as a critical condition for the continuing habitability of the planet, and such fact has been consistently addressed in several international efforts aimed at implementing a universally agreed framework able to support industry development and protect the environment concomitantly.

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The United Nations (UN) Conference on Environment and Development Rio Eco92 - Earth Summit, held by Rio de Janeiro in 1992, can be considered the first global attempt towards a blueprint for sustainable development, with the Agenda 21 proposition. In 2000, UN General Assembly adopted the United Nations Millennium Declaration stating fundamental values among which respect for nature is listed and corroborated by a specific target addressing environment protection. The General Assembly resolution 55/2 reinforced the Agenda 21 environmental relevance and highlighted the fundamental importance of reducing greenhouse gases (GHG) emissions, that should be tackled by the Kyoto Protocol signed in 1997.

The UN World Summit on Sustainable Development Rio+10, held by Johannesburg in 2002, recalled the need for the Kyoto Protocol effective implementation, so that a staggered and consistent GHG emissions reduction could be timely accomplished. In general terms, such protocol embraces all the commitments, obligations, goals and targets under the United Nations Framework Convention on Climate Change.

In order to foster the Kyoto Protocol objectives accomplishment, several regions, countries, states and cities designed and implemented market initiatives targeting GHG emissions reductions and/or financial compensations for above-cap emissions, which includes carbon-trading mechanisms. The United Kingdom implemented its domestic emissions trading scheme in 2002, followed by Norway in 2005; both countries had their schemes incorporated to an European-wide comprehensive framework.

The European Union Emissions Trading Scheme (EU-ETS) was launched in 2005 and initially targeted energy intensive industries (energy generation, mineral extraction, ferrous metals production and processing, and the production of pulp from timber, paper and board). In 2009, ten US states implemented the Regional Greenhouse Gas Initiative (RGGI), a mandatory emissions reduction market based program. Tokyo launched its emissions trading scheme in 2010, after a ten years process that followed the establishment of a carbon emissions reduction program. In 2011, the Canadian provinces of British Columbia, Ontario and Quebec, and the US state of California created the WCI Inc., a non-profit organization linked to the Western Climate Initiative with the purpose of supporting CO2 emissions cap-and-trade systems implementation.

The European Union included within-Europe aviation in the EU-ETS scheme in 2012. In 2003 the International Civil Aviation Organization (ICAO) adopted an Assembly resolution prescribing the establishment of a global market-based mechanism to reduce air transport emissions that should be in force by 2020, which is expected to supersede EU-ETS regulations for aviation.

The United Nations annual climate change conference COP-21 (Conference of the Parties) held in 2015 reviewed some emissions reduction targets and reaffirmed States commitments on environment protection goals, as ratified by the Paris Climate Change Agreement. More recently, in 2017 China, currently the largest emitter of greenhouse gases on the planet, implemented the biggest carbon trading market in the world, initially embracing energy generation based on coal and natural gas.

According to Wang & Wang (2015), carbon emission trading schemes are amongst the most used market measures put in place to support emissions reductions initiatives, and the European Union states that such systems are among the most cost-effective tools for reducing GHG emissions (European Commission, 2018).

Therefore, by considering the unquestionable relevance of emissions trading schemes (ETS) for the sustainable development on the planet, this chapter aims at providing a comprehensive analysis of the EU-ETS implementation, with focus on its design evolution and impacts on the verified emissions, according to the attempted financial strategies and scheme parameters.

The findings presented and discussed hereafter were accrued from the scrutiny of two European Commission (EC) EU-ETS Impact Assessment reports (2014 and 2017), two EC reports on Climate

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Action Progress (2015 and 2016), two European Environment Agency (EEA) indicator assessment on GHG emissions trends and projections (2017 and 2018), eight EEA reports on the emissions trends and projections in Europe (2011, 2012, 2013, 2014, 2015, 2016, 2017 and 2018), seven EEA annual GHG emissions inventory (2012, 2013, 2014, 2015, 2016, 2017 and 2018), two EEA GHG emissions trends analysis (2008 and 2012), and four EEA reports on the EU-ETS emissions trends and projections (2015, 2016, 2017 and 2018). Additionally, the careful analysis of European Union Transaction Log (EUTL), the European Statistics database and the World Bank databases contributed for the depuration and complementation of the information obtained from such sources.

BACKGROUND

After the signature of the Kyoto Protocol in 1997, governments, industry stakeholders and academia began to work on the development of effective and efficient environmentally driven policies and economic mechanisms. In such context, the EU current efforts in support to sustainable development and climate change avoidance comprises three main initiatives, i.e. GHG emissions reduction, consistent increment on energy production from renewables (Renewable Energy Directive - RED), and increase in energy efficiency (Energy Efficiency Directive - EED).

The Renewable Energy Directive (2009/28/EC), revised by the Directive 2018/2001/EU, frames the EU efforts targeting the progressive increment of renewables in the European energy production matrix. As a policy, it states that by 2020 at least 20% of EU energy should come from renewable sources, ensured that at least 10% of the transportation also runs on renewables. The 2018 Directive review established a more ambitious target, i.e. at 32% of renewables in the EU energy matrix by 2030.

The Energy Efficiency Directive (2012/27/EU), currently under reviewing process, enforces EU Members to progressively improve energy use efficiency at all chain stages, from production to final consumption. Among other entities and initiatives, the policy covers energy distributors and retail sales, the public sector (purchase of energy efficient buildings, products and services, energy efficiency driven renovations on existing facilities), the improvement of final users consumption awareness, etc. Similarly to the RED, the EED targets 20% of savings on projected final energy consumption by 2020, and the reviewing process aims at 30% by 2030.

The initiative directly tackling GHG emissions targets a reduction of at least 20% compared to 1990 levels, and is constituted by two main frameworks: the European Union Trading Scheme (EU-ETS), embracing the energy-intensive industry sectors, and the Effort Sharing Directive (ESD), according to which EU States need to meet binding annual greenhouse gas emission targets for the period 2013–2020 in sectors not covered by the ETS, such as building, transport, waste and agriculture. The three targets established by the aforementioned initiatives are commonly referred as the '20-20-20 by 2020' climate and energy targets.

The need to implement the ETS is justified by the new global economic reality in which the environmental cost of all human activities should no longer be neglected, otherwise the environmental degradation caused by greenhouse gas emissions could lead global markets to a vicious cycle of losses caused by climate changes.

Within ETS framework, emissions are supposed to be reduced by means of price-based economically efficient measures. Thus the emissions trading scheme is a framework in which greenhouse gases emitters are enforced to hold tradable allowances in order to cover their emissions (partially or in its entirety). In

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such framework, emissions are usually bounded by caps, and the entities subject to the scheme may either reduce their own emissions or trade allowances so that industry overall emissions limits are respected.

ETS implementation ensures that the emissions cost is included within products' pricing structure, enabling the market to determine industry production optimal levels accordingly. Most importantly, every industry participating segment is granted flexibility to determine its production / emissions levels based on specific abatement costs and output prices.

The ETS design features several parameters, such as emissions thresholds, measurement processes (direct/indirect/estimation), coverage (voluntary/mandatory, geographical area, gases, sectors), approach (baseline-and-credit/cap-and-trade), permit allocation (sale/auction, absolute/relative shares, mature/immature sectors, incumbent/new entrants), action timing consequences (early action credit/non-compliance penalty), trading period duration, market ownership and governance, offset alternatives, international harmonization, etc.

Even though alternatives to ETS include technology push via research funding, information campaigns aiming at voluntary restraint, government subsidies, strict regulatory restrictions and pure taxation, the most relevant emissions reduction initiatives worldwide considered ETS as the primary tool.

The adoption of the Directive 2003/87/EC and the imminent implementation of the European Union Emissions Trading Scheme triggered a consistent and continued wave of studies attempting to project its impacts on both the targeted emissions and the European economy, including economic phenomena such as competition and implications on gross domestic product (GDP). Such ETS implementation impact studies covered diverse scopes; e.g. a specific industry segment, a supply chain, and an extended supply chain (raw material extraction and supply, production, assembly, distribution/transportation, reverse logistics).

Lund (2007), by means of econometric models, projected direct and indirect cost impacts accrued from EU ETS implementation on targeted energy-intensive industries considering Kyoto and post-Kyoto periods prescriptions. ETS was framed as a new expense for the industry and then compared to other relevant expenses. The problem formulation addressed the EU ETS impacts in terms of direct CO2 emissions reduction cost and potentially increased expenses with electricity, both as a percentage of production value. The author projected post-Kyoto ETS related total costs to be four times higher than those projected for the Kyoto period. Steel and cement industries could face 3-4 fold cost impact when compared to pulp-paper and oil refining industries. Electricity-intensive industries outside ETS could also be affected, with projected additional costs reaching 10% of the production value for some sectors (e.g. aluminum and chlorine) yet in the Kyoto period.

Scheelhaase & Grimme (2007) developed an econometric model and empirically estimated the EU ETS implementation impacts on four types of airlines operation in Europe, i.e. low cost carriers (LCC), full service network carriers (FSNC), charter carriers and regional carriers. The model allowed for the estimation of current and future CO2 emissions, costs of acquiring emission allowances and demand side effects dependent upon different airline strategies to pass additional costs onto passengers. The problem formulation considered three potential ETS design options, which differed in terms of geographical range, assumed prices of allowances, initial allocation method, and the assumed emissions growth rates. According to the authors, ETS implementation could produce competition distortions, with LCCs and regional carriers being more negatively impacted than FSNCs.

Barbot et al. (2014) projected the EU-ETS impacts on airlines market competition. More specifically, the authors provided a game-theoretic analysis on incumbent and new entrant airlines potential strategies and decisions under the EU environmental policies, where the airlines' production could be done

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by either acquiring permits or reducing emissions. Basically, the economic competition modeled a la Cournot considered that competing firms simultaneously and independently established the production levels, whilst the demand defined the prices. The authors worked with the premise that the EU ETS was originally designed for application over energy intensive industries (features of natural monopoly - very high entry cost) and its application on such a different industry as air transport could lead to competition distortions. In more details, regarding most of the intensive energy industries, the implementation of an ETS would not change the competition scenario due to its inherent very high entry cost. As regards to air transport, the researchers importantly concluded that the introduction of the ETS could equip incumbent airlines with an additional manipulable variable to accommodate, deter or block new entrants.

Yang et al. (2017) developed a game-theoretical model to study the competition between two independent supply chains under a carbon emissions cap-and-trade scheme considering price and product greening level. Each supply chain consisted of one manufacturer and one retailer, and they were studied according to two different perspectives in terms of decision-making structure, i.e. decentralized, (retailer and manufacturer have independent profit optimizing strategies) and centralized (retailer and manufacturer regarded as an integrated organization aiming at optimizing profit of the whole chain). The authors also considered two specific situations: first, the manufacturers horizontally cooperate aiming at own profit maximization; second, the retailers utilize incentive mechanisms in order to avoid manufacturers cooperation.

The problem formulation considered that the supply chains provided two substitutable low-carbon products and competed on the emission reduction rate and wholesale price in the same market, where higher emission reduction means higher product greening level. Three main conclusions were presented: a) fiercer greening level competition might lower manufactures' emission reduction enthusiasm; b) for vertical interactions, integrated decision would always be a dominant strategy regarding the whole supply chain performance; c) cooperation between manufacturers could reduce retailers profit and hurts consumers' welfare.

Scott et al. (2017) used environmentally-extended multi-region input-output analysis (EE-IOA) to accomplish an ex-post analysis of the emissions embodied in the production and use of products traded in the European Union Market, with the object of getting insights on how to improve EU ETS (and correlated policies). The authors mapped products flows in 2007, from the initial production, passing through the supply chains up to the final consumption. They concluded that EU's emissions related to the supply chain and to the final consumption are respectively 16% and 39% higher than the ones linked to the initial production. Finally, they estimated that 2061 MtCO2-eq (40% of total EU production emissions) were related to material-intensive manufactured products' supply chains, with only 789 MtCO2-eq covered by the EU-ETS.

The aforementioned studies provided important insights on approaches to address some key features of emissions trade schemes and their correlations with global emissions and some economy instances, and also presented some conclusions on potential impacts derived from the scheme implementation.

Therefore, with the objective of better supporting future studies, one finds hereafter an overview of the scheme design evolution in terms of scope, allowances allocation process and emissions cap (among others). Sequentially an analysis on how the EU-ETS features improvements impacted its effectiveness is conducted, with focus on the greenhouse gases emissions trends, the carbon price behavior and some economic issues caused by the inefficient allocation of allowances.

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THE EUROPEAN UNION EMISSIONS TRADING SCHEME DESIGN EVOLUTION

The EU-ETS is the most important European greenhouse gases emissions (GHG) reducing mechanism. Its implementation started in 2005 as the first international emissions trading system, and currently accounts for over three-quarters of worldwide carbon trading. In the current implementation phase, EU ETS is a comprehensive scheme embracing thirty-one countries, more than twelve thousand industry installations and all the airlines operating in these countries, and covers 45% of the European Union GHG emissions, approximately 5% of global emissions.

The Scheme was designed observing a cap-and-trade principle, as such an upper limit on emissions is fixed, and allowance permits are either auctioned out or distributed by the government for free according to specific criteria. The industries covered by the scheme shall surrender one allowance for every CO2 (or the equivalent amount of N2O or PFCs) emitted tone. Allowances may also be acquired from other industry facilities or withdrawn from credits accrued from previous years surplus. The scheme also enforces a non-compliance penalty for operators not surrendering sufficient allowances.

The EU-ETS implementation was ruled by the European Union Directive 2003/87/EC, approved on October 13th, 2003. The directive framed the scheme implementation as prescribed by the European Parliament and Council Decision 1600/2002/EC, which reflected the Community commitment to achieve an 8% reduction in GHG emissions by 2008 to 2012 (Kyoto Protocol first commitment period) compared 1990 levels, as stated by the Decision 2002/358/CE.

The directive prescribed a staggered implementation. Phase 1 (pilot phase) comprised the first three-year period beginning 1 January 2005, within which at least 95% of the allowances should be freely allocated. The emissions cap was set on per-State basis and by a grandfathering method. As such each state should submit a National Allocation Plan (NAP) for assessment by the Commission, who would approve it, or change the amount of allowances to be allocated, in accordance with previous years emissions estimations.

The Directive 2004/101/EC, approved in October 2004, established a link between the European Scheme and the Kyoto Protocol's project mechanisms, such as the Clean Development Mechanism (CDM) and the Joint Implementation (JI) programs. Thus the Directive allowed the acceptance of international offset credits, i.e. the Certified Emission Reductions units (CERs) and the Emission Reduction Units (ERUs), up to a limit of 1.6 billion units between 2008 and 2020.

The EU-ETS pilot phase was characterized by carbon price instability, which arose as a consequence of the over-allocation due to the lack of precise data regarding past carbon emissions. After the first set of emissions data was released, allowances price dropped from €29/tCO2 to €13/tCO2 in May 2006, and by the end of the phase the system registered an allowances surplus of approximately 150 million units, with a carbon price close to €0/tCO2 (de Clara & Mayr, 2018).

Still determined based on NAPs, the phase 2 period (2008-2012) allocation process required that at least 90% of the allowances were freely allocated. Also according to the directive, the total quantity of allowances should be determined for a five-year period from phase 2 on, with the annually issued proportions defined by the regulating authorities. Phase 2 was also characterized by a relevant surplus of allowances.

Between 2007 and 2009 the European 2020 climate and energy legislation package reviewed the GHG emissions reduction goals, and set the EU target at 20% by 2020 compared to 1990, which represented a 14% decrease compared to 2005. (European Commission, 2015a). In order to accomplish such updated

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global EU target, emissions under the EU-ETS framework should observe a 21% reduction compared to 2005, and the scheme design was subject to improvements effective during the implementation phase 3.

Therefore the cap setting and the allowance allocation process in the current phase 3 featured significant changes. An annual cap linear reduction factor of 1.74% was introduced to ensure that emissions on 2020 are 21% of 2005 levels. Auctioning replaced free allocation as the default method, such that by the end of the phase no more than 43% of the allowances are freely allocated. Thus power generation sector installations, with few exceptions, were forced to buy 100% of its allowances from 2013 on, and the other industry sectors were subject to a progressive reduction in the quantity of allowances allocated free of charge.

In phase 3 even the distribution of non-auctioned allowances became more stringent. The free allocation process based on National Allocation Plans on per-State basis was replaced by an EU-wide cap definition driven by National Implementation Measures (NIMs) proposed by each State, as prescribed by the Decision 2011/278/EU.

Moreover the grandfathering (free allocation) estimation method was replaced by the benchmark. According to this new estimation method, the total quantity of allowances to be freely allocated to an installation should be determined by product-related GHG emissions benchmarks, which are set at the average emission level of the 10% most efficient installation in each sector. The industry installations then were granted 80% of the benchmark for free in 2013; such percentage yearly decreases towards 30% in 2020. However, industries deemed to be highly exposed to carbon leakage risk are continuously granted 100% of their allowances needs for free. The aviation sector benchmark was defined in a different way, though (European Commission, 2015b).

In order to effectively manage the resources accrued from the auctioning process in phase 3, the Commission established clear criteria for the auctioning rights distribution, i.e.: a) 88% of the total auctionable allowances is distributed to all Member States according to their GHG emissions share during phase 1; b) 10% is divided among Member States with low per capita income receiving a larger share compared to the ones with high per capita income; c) 2% is distributed to Member States that by 2005 had already achieved an emissions reduction of at least 20% compared to Kyoto Protocol reference year level.

According to the Directive 2003/87/EC at least 50% of the revenues accrued from the allowances auctioning should be used in support to climate changes avoidance initiatives, either within EU or in developing countries. In 2008, the Heads of State declaration at the European Council reinforced the commitment, and it was agreed that at least 50% of the auctions' revenue would be driven to GHG emissions reduction projects. In 2015, the European Parliament and Council Decision (EU) 2015/1814 created a Market Stability Reserve (MSR) to be in force from January 2019 on.

Additionally, phase 3 featured a New Entrants Reserve (NER) fund aimed at avoiding negative impacts on industry expansion and competition, by which up to 5% of total permits were to be freely allocated for new entrants and installations with significantly increased production capacity.

Regarding phase 4 (2021-2030), the European Council, in October 2014, established a new 2030 framework for climate and energy, by which domestic emissions reduction targets were reviewed and set to 40% by 2030, 60% by 2040 and 80% by 2050 in relation to 1990 levels. In order to cope with the new target, in July 2015, the European Commission reviewed the EU-ETS target and the annual cap linear reduction factor, respectively set to 43% by 2030 compared to 2005 levels, and 2.2% from 2021 onwards. Table 1 summarizes EU-ETS design evolution up to phase 3.

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Table 1. EU ETS design evolution

Phase	Scope			Cap Setting				Allowances Allocation Methods	Interphase Banking	Non-compliance Fee (€)	Eligible Trading Units[12]
	Geography	Sectors	GHGs	Allocation Perspective	Designed Cap (Annual in MtCO2)[5/6] (Stationary Installations)	Emissions Level Target (% of 2005 level)[9]	Cap Linear Reduction Factor (% of the previous year)				
1 (2005/2007	EU-27[1]	Power stations and other combustion plants ≥20MW; Oil refineries; Coke ovens; Iron and steel plants; Cement clinker; Glass; Lime; Bricks; Ceramics; Pulp; Paper and board.	CO2	National Level	2058[7]	-	-	Free Allocation (Grandfathering) (~100%)	Not Allowed	40	EUAs
2 (2008/2012)	EU-27, Norway, Iceland, Liechtenstein[2]	Same as phase 1 plus Aviation[4] (from 2012).	CO2 N2O (Opt-in)	National Level	1859[7]	8.4	-	Free Allocation (Grandfathering) (~96%) Auctioning	Allowed	100	EUAs CERs ERUs
3 (2013/2020)	EU-28[3], Norway, Iceland, Liechtenstein	Same as phase 1 plus Aluminum; Petrochemicals; Ammonia; Nitric, adipic and glyoxylic acid production; CO2 capture, pipeline transportation and geological storage; Aviation in Croatia (from 2014).	CO2, N2O, PFC from aluminum production	EU Level	2084[8]	21	1.74	Auctioning (~57%) Free Allocation (Benchmark)[10/11]	Allowed	100 plus inflation from 2013 on	EUAs CERs ERUs

Observations

1. Bulgaria and Romania joined the EU in 2007.
2. EU ETS geographical scope included the European Economic Area entirely.
3. Croatia joined the EU in 2013.
4. EU ETS scope limited to flights within the European Economic Area.
5. 5% of the total quantity of allowances is reserved for free allocation to new entrants.
6. Aviation was set a provisional cap of approximately 210 MtCO2 per year from 2013 on.
7. The annual cap was set in a bottom-up method based on the National Allocation Plans (NAPs) provided by the European Community (EC) Member States; the national emissions cap prescribed by the NAPs were defined in accordance with the EC Decision 2002/358/CE, by which the Kyoto Protocol was internally adopted and the Community States agreed on a joint emissions reduction of 8% compared to 1990 levels, by the first Kyoto Protocol Commitment Period (2008-2012).
8. The cap was centrally set for 2013 and covered all 28 EU Member States, decreasing linearly by 38 MtCO2 per year.
9. The values represent the derived EU-ETS contributions estimates, with reference to 2005 emissions levels, in support to the achievement of global EU emissions reductions with reference to

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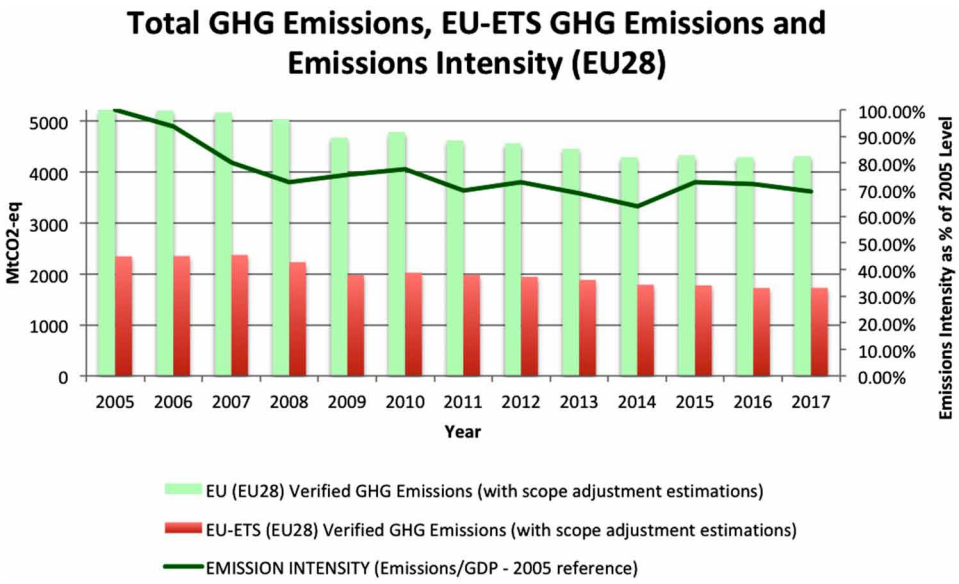
Figure 1. Historical GHG emissions with scope adjustment and emission intensity of the EU economy, based on the European Union Transaction Log (EUTL) database



1990, i.e.: a) phase 2 - 8% of reduction for EU15; b) phase 3 - 20% of reduction; c) phase 4 - 40% of reduction.

10. Free allocation is limited to approximately 43% of the total cap during phase 3; power generation installations are obliged to buy all their allowances from 2013 on, with few exceptions that were granted to receive it for free up to 2019; other industry sectors will be granted free allowances in a yearly decreasing fashion, starting with 80% of the total allocated allowances in 2013, reaching 30% in 2020, with plans to be 0% in 2027.
11. Free allocation driving method changed from grandfathering to benchmark.
12. During phase 2 credits from forestry, and large hydropower projects were not eligible. During phase 3, CERs and ERUs from forestry, HFC, N2O or large hydropower projects were not eligible. Only least developed countries projects related CERs were eligible from 2012 on.

EUROPEAN UNION EMISSIONS TRADING SCHEME EFFECTIVENESS ANALYSIS

According to the recent EEA Indicator Assessment on GHG emission trends and projections (European Environment Agency, 2018a), total EU GHG emissions reductions, excluding those ones deriving from land use, land use change and forestry (LULUCF), reached 22.4% and 21.9% bellow 1990 levels in 2016 and 2017 respectively.

The 2017 reduction is equivalent to 15.3% bellow 2005 levels, while GHG emissions from sectors covered by the EU-ETS in the same year were 26.4% below 2005 levels, when considering scheme scope adjustment of approximately 331 MtCO2 for 2005. The EU GDP though grew by approximately 53% between 1990 and 2016. The European Union emission intensity with reference to the EU GDP

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decreased by almost 50% between 1990 and 2014 (European Commission, 2015a). Figure 1 presents both emissions and emissions intensity of the economy trends between 2005 and 2017. When considering 2005 as reference, emissions intensity in 2017 is approximately 30% lower.

Thus it is possible to imply that the EU continues to successfully decouple GHG emissions and GDP, and it is clear that the emissions intensity of the European economy had a marked decrease that reflected, to some extent, the systematic and consistent greening efforts addressing GHG emissions, as well as energy production and efficiency. However, additional factors contributed for the occurrence of such phenomenon.

The reductions on GHG emissions and emission intensity of economy accomplished since 1990 is attributed to a combination of several factors, e.g. use of renewables, less carbon intensive fuels, improvements in energy efficiency, economy structural changes and economic recession. An increased contribution of services and a lower share of the energy-intensive industries for total GDP, in association with the 2008 economic crises are amongst the most influential reducing factors. According to the World Bank database, the value added by EU industry (as percentage of its GDP, with reference to basic prices) decreased from about 29% in 1990 to 21.98% in 2017, when services and industry respectively contributed with 74% and 25.6% of EU GDP (with reference to purchase prices).

Along with the 2008 economic crisis and the structural shift observed in the European economy, the GHG emissions reduction accomplished by the EU are mostly due to contributions provided by the power generation / fuel combustion sector, throughout all European climate change avoidance initiatives. Hereafter then it will be demonstrated that it was particularly true for the EU-ETS.

EU-ETS GHG Emissions Trends

In 2005 EU-ETS emissions represented approximately 45% of EU verified emissions, while in 2017 such coverage comprised 40% of the total, when its reduction reached 26.4% of 2005 levels, which is already below the 2020 reduction target.

When considering the scheme scope adjustment, the EU-ETS emissions presented an almost continuous decrease trend throughout its phases, as can be observed in figure 2. The scope adjustment was designed to reflect the evolution of the scheme coverage, as previously described in Table 1, and as such, it compensates for the increment in the number of States, installations and gases observed within 2005-2012.

Notwithstanding the overall marked reduction, the industry sectors' contributions for the trend were not proportional. Figure 3 demonstrates that the overall reduction was due to the power generation segment contribution. The segment is the greater emitter, responsible for approximately 66% of EU-ETS emissions in 2017, which represents a clear evolution from the 72% contribution in 2005.

Overall EU emissions related to the production of heat and electricity decreased from 4355 MtCO2 in 1990 to 3352 MtCO2 in 2016. Energy efficiency itself has notably improved, i.e. in 2005 EU production marked more than 900 Mtoe, with a consistent decrease trend leading to approximately 760 Mtoe in 2015 and 755.4 Mtoe in 2016 (European Commission, 2019).

Specifically regarding the installations under the EU-ETS, in addition to the contributions verified during phase 1 and 2, the power sector decreased its emissions from 1345 MtCO2 by the end of 2012 to 1148 MtCO2 in 2017, or 14.65% in 5 years, equivalent to a reduction of 20.44% compared to 2005 levels, not considering the scope adjustment. The continued power sector decrease trend, in contrast to the other stationary installations trend, may be explained by a combination of two possibly correlated factors, i.e. changes in the energy source mix and a differentiated policy for carbon allowances allocation.

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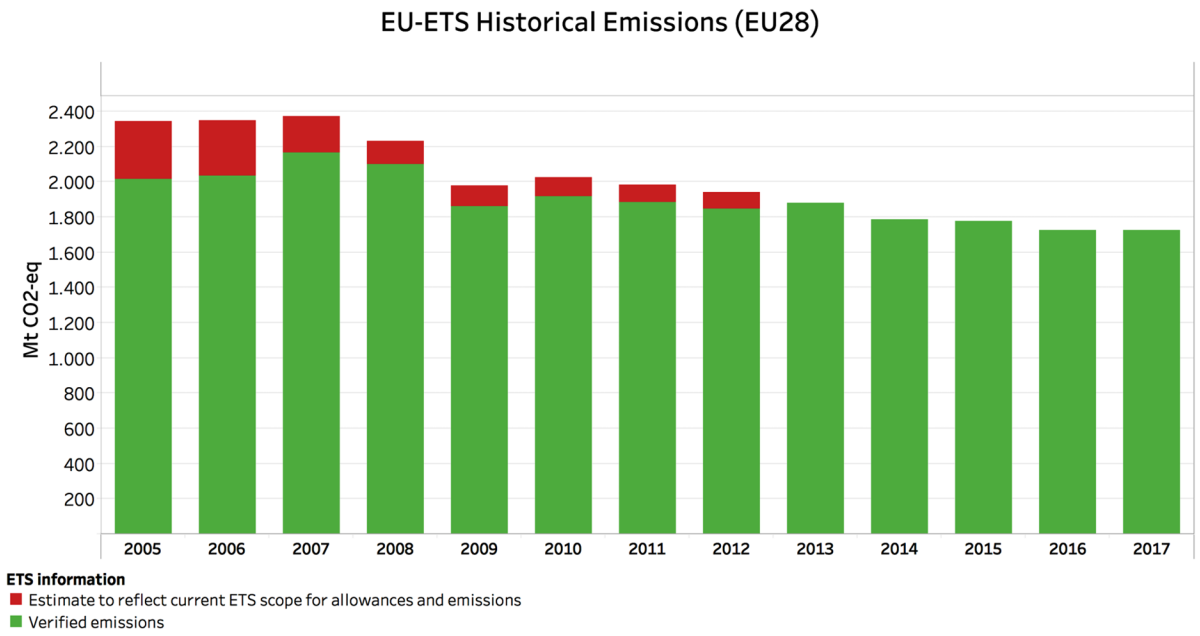
Figure 2. EU-ETS historical emissions with scope adjustment, based on the European Union Transaction Log (EUTL) database



The energy sources mix is continuously shifting to greener profiles; in 2005 renewables and fossil fuels (coal, oil, and natural gas) represented approximately 13.3% and 57.3% of the energy matrix, reaching 27.9% and 41.5% by 2016. In the same year, approximately 30% of the electricity consumed in the EU derived from renewable sources (RES), with the RES mix mainly composed by hydropower (36%), wind (32%), solar photovoltaic (12%), and solid biomass (European Environment Agency, 2018d).

And although solid, liquid and gaseous biofuels still provide the largest share of total renewable energy, being heavily used in heating, electricity generation and transport, wind and solar energy relative shares are consistently rising: in 2016, the EU produced 26.0 Mtoe from wind energy, more than fivefold increase compared with 2004; in the same year, solar energy (photovoltaic and thermal) provided 13.4 Mtoe, more than 19 times as much as in 2004 (European Commission, 2019).

The aviation segment still contributes with a small part of to EU-ETS emissions, however it currently shows a sharp increase trend. Estimates contained in the EEA Annual EU GHG Inventory 1990-2016 and Inventory Report 2018 indicate that worldwide international aviation emissions increased 115% between 1990 and 2016 (European Environment Agency, 2018b). During phase 3, so far, EU-ETS aviation emissions showed a consistent increase trend, with a variation of approximately 21.5% between 2013 and 2017.

The aviation permits (EUAA) distribution was practically set on a fixed basis for the current EU-ETS phase, i.e. 36 MtCO2 annually, with 82% of the permits allocated for free, 15% distributed by auctioning, and 3% reserved for distribution to fast-growing aircraft operators and new entrants. When considering EU28, phase 3 allowances supply for aviation covered so far 64.7% of its needs; as a consequence, the aircraft operators had to buy and surrender EUAs as complement, with annual figures around 17 MtCO2. Thus, the aviation industry did not have relevant influence on global EU-ETS performance.

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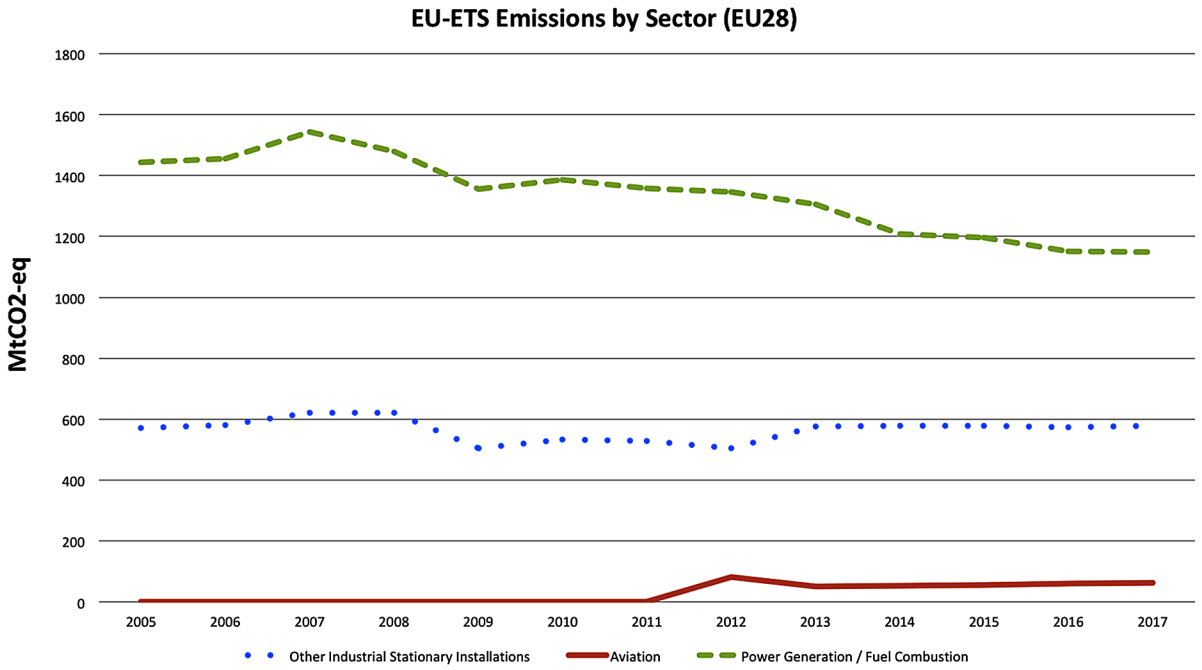
Figure 3. EU28 emissions by industry sector, based on the European Union Transaction Log (EUTL) database



The other industrial stationary installations had a reduction right after the 2008 economic crises, which was followed by a rebound to pre 2008 levels by the end of 2013; since then such emissions remained practically stable. According to the European Environment Agency (2018a), the uncertainty for GHG emissions calculation is about 6% and for trends calculation is 1%.

Figure 4 allows a more detailed analysis of the other stationary installations emissions trends. Cement and steel related industries presented an important emissions reduction during EU-ETS first two phases, which was followed by stagnation around 150 MtCO2 in the third phase. Chemical industries in turn presented a marked increase and reached almost 80 MtCO2 in 2017, which provided compensation for the cement and steel industries reductions.

Therefore, it is clear that the EU-ETS did not effectively drive GHG emissions reduction among installations outside the energy sector, and the scheme policy for the allocation of allowances might give some clues about such phenomenon. According to the EEA 2018-14 report (European Environment Agency, 2018c), in 2017 the installations producing iron and steel, coke, and metal ore, as well as the ones producing pulp, paper and cardboard had a substantial balance of free allocations compared to verified emissions, while the plants producing cement and lime, and chemicals had parity. Such conditions may partially explain the trends shown in Figure 3, as discussed hereafter.

EU-ETS Allowances Allocation Issues

In phase 1, the pilot phase, the absence of reliable data on actual emissions and consequent wrong estimations led to allowances surplus that drove its price to zero by 2007. 6370 MtCO2-eq allowances

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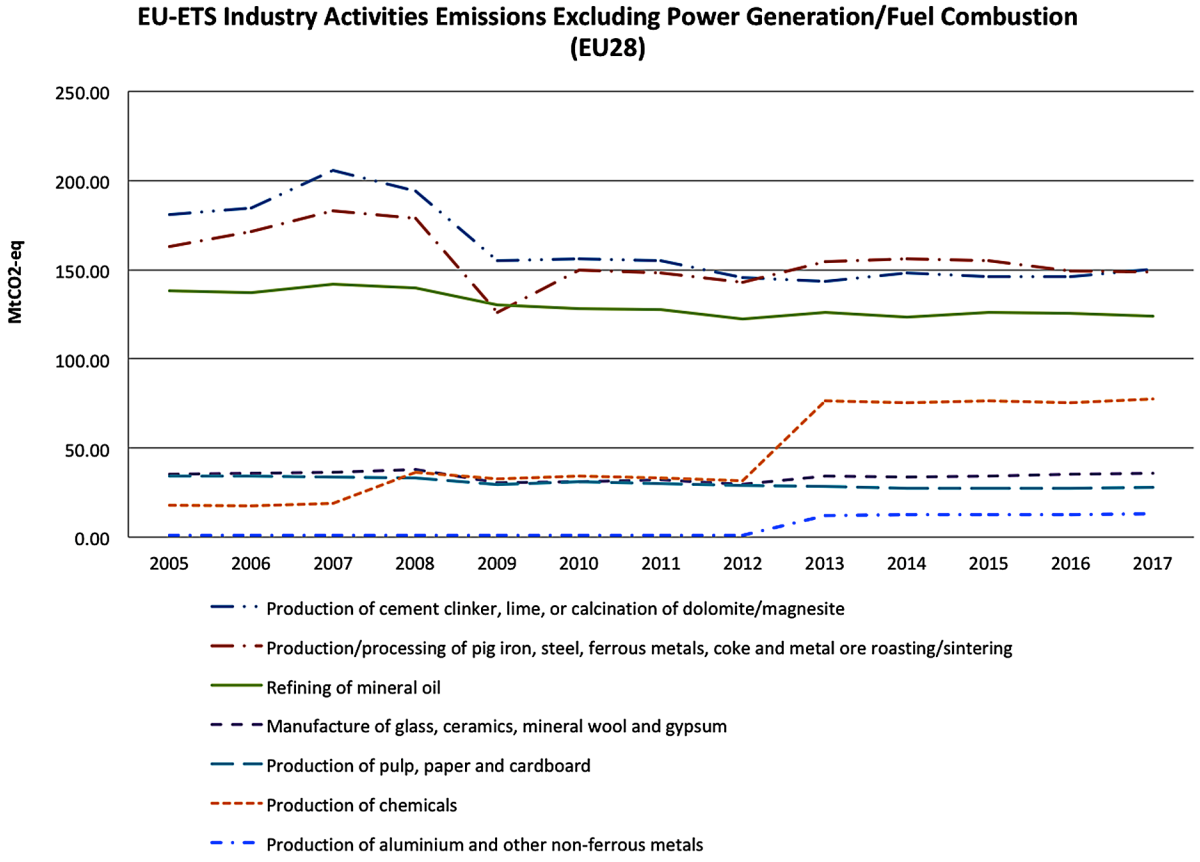
Figure 4. EU28 emissions by industry segment, excluding the power generation sector, based on the European Union Transaction Log (EUTL) database



were allocated between 2005 and 2007, for emissions of approximately 6215 MtCO2. In such scenario, carbon price dropped to near €0/tCO2, hence the scheme did not drive a consistent industry greener trend nor presented significant cost-effective results during the pilot phase. During this phase the EU-ETS covered approximately 45% of total EU GHG emissions and presented an increase trend, despite the slight reduction observed on total EU emissions.

Phase 2 had a marked reduction on emissions. With reference to 2005 levels, by the end of phase 2 first year EU-ETS installations emitted 5% less; by the end in 2012 its emissions were 17% lower. Nevertheless such relevant reduction shall be put under perspective, because when the emissions intensity indicator is taken into consideration, it becomes clear that the reduction was mostly due to lower production levels driven by the 2008 economic crises. As can be observed in Table 2, the emission intensity of the economy was 72.90% in phase 2 first year and 72.92% in its last year, while EU-ETS contribution to EU emissions as a whole remained stable around 42%.

Therefore, although reliable emissions data were available in phase 2, a new large surplus of allowances and credits once again heavily impacted carbon prices. Along with the 2008 economic crises, the Directive 2004/101/EC also contributed to the persistence of such undesirable market imbalance. Total allowances allocation, comprising EUAs, CERs and ERUs, achieved 11373 MtCO2e whilst verified

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Table 2. EU total emissions, EU-ETS emissions, Emissin Intensity and EU-ETS covered emissions contribution to EU emissions (EU28, excluding LULUCF), based on the European Union Transaction Log (EUTL) and the World Bank databases

Year	EU (EU28) Verified GHG Emissions (with scope adjustment)	EU-ETS (EU28) Verified GHG Emissions (with scope adjustment)	EMISSION INTENSITY (Emissions/GDP - 2005 reference)	EU-ETS Emissions Coverage
2005	5220	2345	100.00%	44.92%
2006	5208	2351	93.58%	45.14%
2007	5160	2371	80.23%	45.95%
2008	5042	2230	72.90%	44.23%
2009	4673	1977	75.60%	42.31%
2010	4777	2024	77.81%	42.37%
2011	4620	1984	69.66%	42.94%
2012	4557	1943	72.92%	42.64%
2013	4462	1882	68.48%	42.18%
2014	4291	1787	63.71%	41.65%
2015	4319	1776	72.80%	41.12%
2016	4293	1724	72.01%	40.16%
2017	4317	1727	69.12%	40.00%

emissions registered 9613 MtCO2. Such oversupply of allowances and the consequential carbon low price continued to negatively impact the scheme effectiveness in terms of emissions reduction accomplishment.

As a whole, the first EU-ETS two phases were marked by difficulties in stabilizing of the carbon price, when the total allocated allowances registered an annual average of approximately 2088 MtCO2, and verified emissions registered an annual average of approximately 1978 MtCO2. In the same period the volume of auctioned allowances (EUA) increased from 0 to 115 MtCO2, while 663 MtCO2e CER and 375 MtCO2e ERU were injected in the market, what clearly contributed to the undesirable and persistent surplus of allowances. By the end of 2012, more than 1 billion allowances were rolled over to the next phase and, in such scenario low-carbon investments were postponed. Figure 5 presents the progression of the verified emissions, allowances allocation and carbon price for phase 2 and phase 3 up to 2017.

These findings led the European Commission to carry out a thorough review of the system in order to improve its effectiveness for the third and current phase. Auctioning and benchmark respectively replaced free allocation and grandfathering as driving principles for allowances allocation. Hence in the first year of phase 3 the volume of auctioned allowances soared to 1103 MtCO2.

In order to address the persistent allowances surplus, the Commission followed some other strategies such as back-loading, cap and annual linear reduction factor review, scope extension, restriction on international credits utilization and the implementation of discretionary carbon price management mechanisms. Additionally, the power sector installations were enforced to buy all of the required allowances.

A back-loading measure enforced by the Commission regulation (EU) 176/2014 postponed the auction of 900 million allowances, initially planned to be available between 2014 (400 million), 2015 (300 million) and 2016 (200 million), and supposed to be back on market in 2019 (300 million) and 2020 (600 million). The allowances surplus then started to decline in 2015, when the European Union emitted 10% of world GHG emissions, and kept declining for the next two years.

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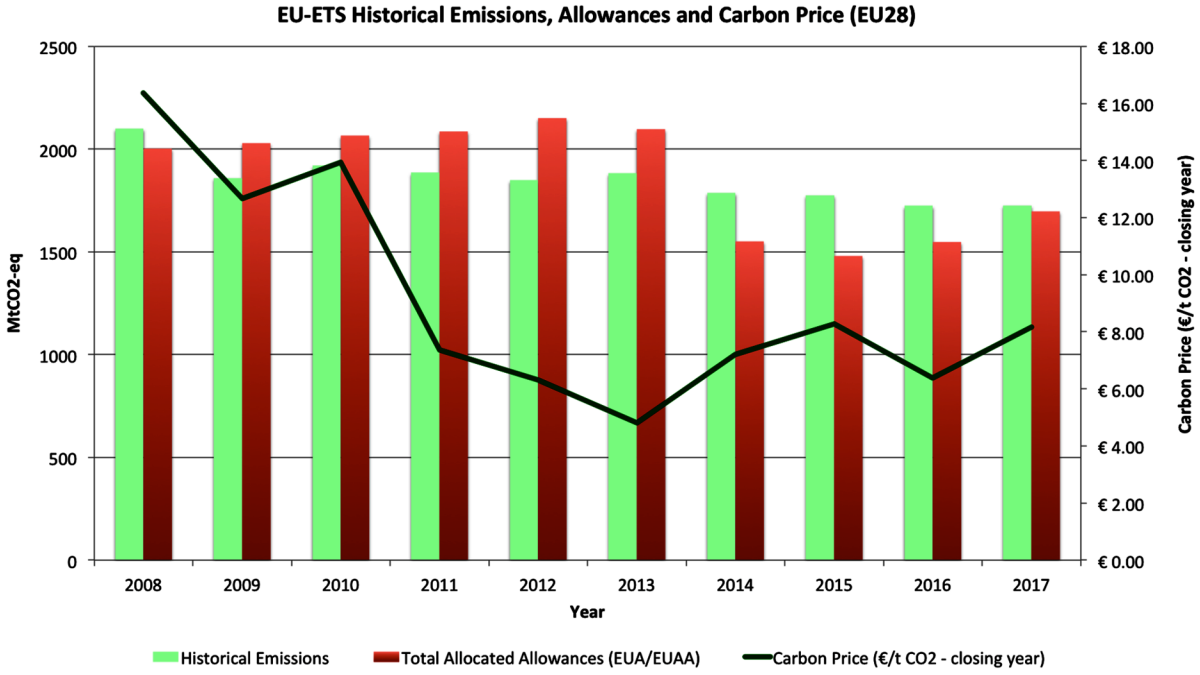
Figure 5. EU-ETS historical emissions, allocated and surrendered allowances, and carbon price 2005-2017, based on the European Union Transaction Log (EUTL) database



Nevertheless, the drastic reduction on the amount of permits allocated for free and the change from grandfathering to benchmark as the free allocation driving policy did not immediately impact the permits surplus nor the carbon price. In 2017 the allowances surplus still was about 1.6 billion, and this substantial structural supply-demand imbalance keeps distorting the market and compromising the scheme effectiveness as an emissions reduction driver, e.g. other stationary installations emissions are stagnated near 2005 levels.

Such scenario compelled the EU to put in place, from 2019 on, the Market Stability Reserve (MSR), a market resilience-improving mechanism that incorporated the aforementioned back-loaded allowances (European Environment Agency, 2018c). The MSR aims at neutralizing the allowance surplus negative impacts, and at improving the system's resilience to future shocks. Thus an automatic rule-set process will adjust the annual supply of allowances to be auctioned when the number of units in circulation is outside a predefined range, i.e.: a) whenever the surplus exceeds 833 million units, 12% of the allowances in circulation are to be placed in the MSR instead of being auctioned; b) whenever the surplus is less than 400 million units, 100 million allowances are to be released from the MSR via future auctions. The Decision (EU) 2015/1814 even prescribed that the back-loaded permits supposed to re-enter the market in 2019 and 2020, as well as unused NER permits were directly deposited in the MSR.

Besides the lack of accurate emissions information during the pilot phase and the unforeseen economic crises during phase two, it is difficult to state clearly the reasons why the EU-ETS governance framework was not able to address properly the persistent structural market imbalance. Nevertheless, a study developed by the International Emissions Trading Association (IETA) indicates that the effects accrued from the RED and the EED might have contributed for such distortion. According to the IETA

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estimates (International Emissions Trading Association, 2015), for the period between 2008 and 2020, EED contribution for the surplus could reach about 515 MtCO2, while RED could have reduced the demand for allowances in approximately 210 MtCO2. Therefore, the lack of proper assessment on environmental policies overlapping effects should be considered as one of the reasons why the EU-ETS performance is not as expected.

Finally, the EU-ETS features in support to the avoidance of carbon leakage also seem to be jeopardizing the scheme effectiveness by contributing for the persistence of the allowances surplus. The list of flaws may include the inadequate criteria for the definition of the industry segments exposed to carbon leakage risks, and an overestimating process for allowance allocation.

By the end of the current phase though, a combination of factors positively impacted the carbon market. The scheme design improvements put in place during phase 3 combined with the adjustments planned for phase 4 seem to have effectively addressed the concerns towards the structural allowances surplus, which motivated market speculation on the increasing need for permits to cope with ascending industrial output levels. As a result, EUA prices soared from €5.52/tCO2 in January 2017 to €24.10/tCO2 in December 2018. However, the emissions figures for 2018 are yet to be published, thus it is not possible to assess how the carbon prices recent upward movement impacted the EU-ETS emissions trend.

EU-ETS Economic Issues

As discussed previously, EU-ETS first two phases induced market distortions, when allowances over allocation, mainly of free permits, kept negatively impacting the scheme effectiveness as well as allowing for undesirable microeconomic outputs. The persistent surplus of allowances dragged permit prices into a consistent decrease trend, as shown in figure 5, which perversely slowed down the adoption of low carbon technologies and processes. Over allocation also provided a relevant additional source of profit for most companies. According to de Bruyn et al. (2016), between 2008 and 2012, the 15 studied energy-intensive industry segments under the EU-ETS profited an additional 8 billion euro by selling permits over allocated for free.

Furthermore, the firms were able to profit from passing through the opportunity costs of permits allocated for free, and such phenomena had an extremely undesirable consequence, i.e. it turned the scheme into a perverse assets transfer system, in which customer's income feeds companies' windfall profits. According to the EEA Report 2018-14, during the first two implementation phases, the power sector accomplished to pass through the costs of the freely obtained emission permits and gained windfall profits.

Regarding to the pilot phase, the studies conducted by de Bruyn et al. (2010) indicated that the prices of products from iron and steel, refineries and chemicals industries were significantly influenced by EUA prices. The authors provided evidence that the iron and steel industry passed through into steel products prices (hot and cold rolled coil) the costs of their freely allocated permits, with a cost-pass-through (CPT) rate of 2.20 (€2.20 product price increase for every €1 EUA price increase). The study estimates also indicate that the refineries as well were able to put in place a 100% cost-pass-through of their freely obtained allowances for gasoil, diesel and gasoline.

The findings related to the chemicals industry demonstrate a 100% CPT for polyethylene and polyvinyl chloride, and a partial 33% CPT for polystyrene. However, is this segment the price adjustments took a much longer lag when compared to iron/steel and refineries, which may suggest a supply-chain effect due to the prices adjustments imposed by the refineries and the power sector.

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Table 3. Cost-pass-through rates - 2008/2014 (Bruyn et al., 2016)

Industry Segment	CPT rate		
	Minimum	Average	Maximum
Extraction of crude petroleum and gas	40%	70%	100%
Manufacture of coke oven products	55%	75%	100%
Refineries	40%	70%	100%
Industrial gases	0%	0%	0%
Inorganic chemicals	10%	24%	37%
Petrochemicals	15%	50%	100%
Fertilizers	10%	50%	100%
Manufacture of plastics	42%	70%	100%
Flat glass	0%	40%	80%
Hollow glass	30%	55%	80%
Other glass	24%	50%	80%
Manufacturing of brick	30%	40%	80%
Cement	20%	39%	58%
Lime	0%	40%	80%
Iron and Steel	55%	75%	100%

As regards to CPT during phase 2 and the first two years of phase 3, de Bruyn et al. (2016) expanded their previous study scope and analyzed the 15 segments in which the top-20 emitters are placed, and the results are summarized in Table 3.

Assuming the minimum CPT rates presented in Table 3, the authors concluded that the industry segments within the study scope accrued additional profits of approximately 15 billion euro between 2008 and 2014. When the average CPT rate is assumed, the estimate jumps to 26 billion euro.

During this period, companies windfall profits were even inflated by the practice of surrendering the cheaper international permits issued by the CDM project. Within this context, between 2008 and 2012, the top-15 emitting sectors distributed in 19 countries used the cheaper CERs for compliance and sold their freely obtained EUAs, which led to additional profits of about 630 million euro. (de Bruyn et al., 2016)

Therefore, for the first two EU-ETS phases, allowance allocation process did not fulfilled its expected purpose of assuring minor impacts on trade and competitiveness. Instead, it transferred customer income to the industries segments and impeded the strengthening of the European resources aimed at fostering greener technologies, as prescribed by Directive 2003/87/EC, according to which at least 50% of the revenues accrued from the allowances auctioning should be used in support to climate changes avoidance initiatives. Regarding phase 3, as previously discussed, the allowances surplus seems to keep a decrease trend, despite the fact that allocation process in place was largely based on pre-recession activity levels.

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OUTLOOK

The EU three main climate changes avoidance initiatives were subject to important reviews, and the 20-20-20 by 2020 strategy targets, as previously discussed, were updated to at lest 32% share of renewable sources, 32.5% improvement in energy efficiency (compared to 2007 energy baseline scenario) and GHG emissions reduction of at least 40% (compared to 1990 levels), all by 2030. Such new EU targets combined with the EU-ETS flaws acknowledged so far led to some important scheme design adjustments, which conform the scenario with additional planned measures (WAM scenario), as listed below.

- **Cap Definition:** annual linear reduction factor increased to 2.2%.
- **Allowances Management:**
  - MSR intake rates doubled for the first 5 years of operation;
  - An invalidation mechanism will allow allowances in the MSR to be cancelled from 2023 on;
  - States will be able to opt for the cancellation of allowances to compensate for the closure of electricity generation installations in their territory;
  - In order to cope with technological progress, benchmark values will be reviewed twice between 2021 and 2030;
  - Allocation process will include a possible annual adjustment in terms of free allocation/auctioning proportion triggered by production changes greater than 15% compared to the initial level, on the basis of a two-year rolling average; and
  - Free allowance allocation to industry segments deemed as not exposed to carbon leakage risk will be subject to a linear phase out converging to zero by 2030.
- **Carbon Leakage Policy:**
  - The number of industry segments classified as exposed to such risk will be reduced;
  - The auctioning share might be conditionally lowered by 3% up to a maximum of 150 million allowances in order to avoid the application of the cross sectoral correction factor; and
  - The annual benchmark reduction rate shall lie between 0.2% and 1.6%.
- **New Entrants Reserve:**
  - 150 million phase 3 unused allowances will be transferred to the reserve; and
  - 200 million MSR allowances will be transferred to the reserve.
- **Green Initiatives Funding:** two funds will be established in order to accelerate the industry transition to a low-carbon economy.
  - Innovation Fund - aimed at fostering innovative technologies addressing industry processes decarbonization, carbon capture and renewable energy;
  - Modernization Fund - aimed at the modernization of energy systems in order to increase energy efficiency in the ten lower-income Member States, including investments to support a socially 'just transition' to a low-carbon economy.

Many of the aforementioned EU-ETS changes are intended to equip the scheme with the required flexibility to deal with business and economic scenario changes and still keep the carbon market balance. For instance, the possibility to annually adjust the allowances allocation process in accordance with the industry production levels is key for the scheme to readily and properly react to economic shocks. And as a whole, the scheme phase 4 improvements are expected to strengthen the carbon price increase trend

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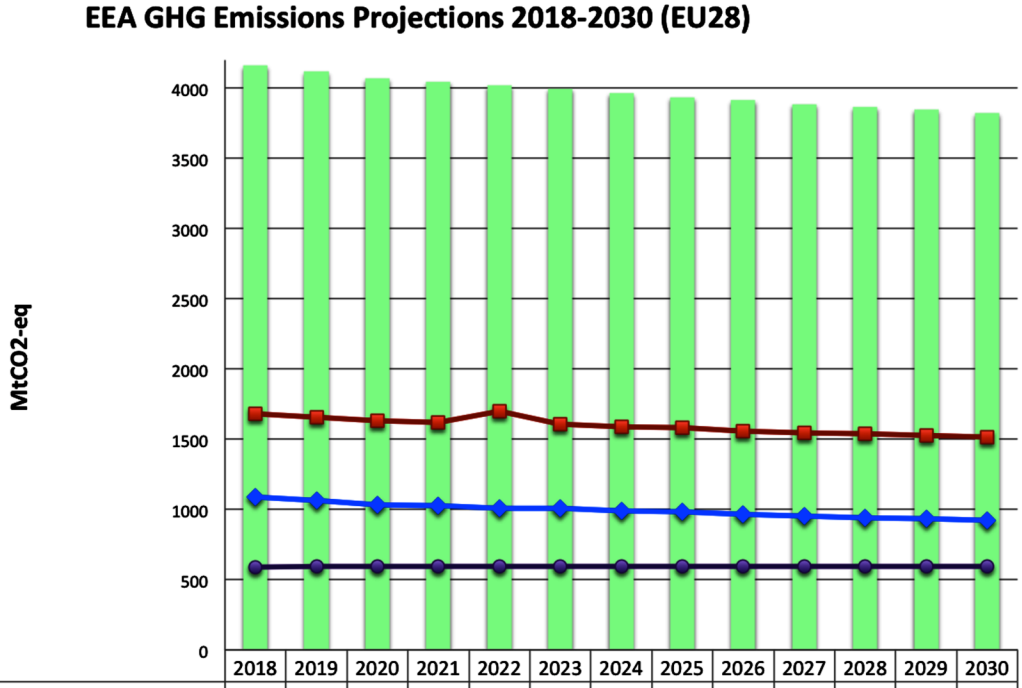
Figure 6. EEA EU28 emissions projections 2018-2030 (European Environment Agency, 2018d)



	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total Emissions	4161	4119	4071	4048	4019	3999	3965	3937	3914	3888	3867	3849	3824
Total EU-ETS Emissions (Stationary Installations)	1680	1656	1630	1623	1698	1605	1588	1580	1556	1549	1539	1527	1516
Power Generation Emissions	1090	1062	1032	1026	1011	1008	990	983	967	952	943	933	923
Other Stationary Installation Emissions	590	594	598	597	597	597	597	598	597	597	595	594	593

started in 2016. The European Commission, Council and Parliament expectations converge to a price varying between €30/tCO2 and €35/tCO2 in 2025 (de Clara & Mayr, 2018).

With the existing measures (WEM scenario), the energy sector might keep contributing for the total emissions reductions. Such expectations are backed up by some important facts: a) coal power still accounts for approximately 40% of total EU emissions, thus there is room for reductions; b) the energy matrix keeps consistently evolving towards the increased use of RES, with rising trends on solar and wind sources use. The share of RES energy in the EU's gross final energy consumption has almost doubled since 2005 and reached 17.0% in 2016, exceeding the indicative EU trajectory set out in the RED (13.8%), and there is no reason to believe that such tendency will change, although a slower pace is expected. The other stationary installations emissions in turn are expected to remain stagnated in the same levels observed in phase 3 (European Environment Agency, 2018c).

Aviation emissions covered by the EU-ETS in 2017 reached approximately 62 MtCO2 (EU28), which represents a 5% increase compared to 2016, and about 3.5% of the total emissions covered by the scheme in that year. Regardless of the sector continued deficit in terms of allowances versus verified emissions, increasing air transportation demand supports the projections according to which, in a WEM, the aviation emissions will sustain a consistent increase trend, and the net demand for allowances in the sector is also expected to rise. Figure 6 presents the EEA 2018-2030 projections for total EU and EU-ETS GHG emissions, WEM scenario and excluding aviation.

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Notwithstanding the planned EU-ETS design evolution and the accompanying policy improvements as regards to the Effort Sharing Decision (ESD), the Renewable Energy Directive (RED) and Energy Efficiency Directive (EED), and the positive projections for the carbon prices, the EU member States' projections, as registered in the EEA Report 16/2018 (European Environment Agency, 2018d), converge to an 30% EU-wide total GHG emissions reduction compared to 1990 levels by 2030, with existing mitigation measures (WEM scenario), and 32% when considering a WAM scenario. Thus, the latest reduction estimates fall short of the 40% target for 2030.

Specific EU-ETS projections indicate that the stationary installations might accomplish a 5% reduction between 2017 and 2020, and 7% between 2020 and 2030 in a WEM scenario, still expecting energy sector to contribute the most. The 2020-2030 reduction projection may reach 10% for a WAM scenario, which is insufficient for the accomplishment of the 2030 reduction target of 43% compared to 2005.

Therefore the achievement of 2030 targets will require additional policies and new comprehensive and creative approaches, which shall comprise EU-ETS design improvements tailored to overcome its persistent ineffectiveness in reducing the aviation and the other stationary installations emissions.

CONCLUSION

Environmental protection is being progressively considered as paramount condition for the planet's continued habitability. In the 21st century reality, development and sustainability can no longer be treated independently, and all environment protection initiatives shall be supported. Such scenario compels the governments, business community and academia to work together with the objective of designing and implementing mechanisms that simultaneously promote economic development and environmental sustainability.

The Emissions Trade Scheme (ETS) is a promising mechanism intended to support the accomplishment of this objective, currently considered as one of the most used and cost-effective tools for reducing CO2 emissions. However, according to the literature, ETS implementation may cause undesirable market distortions, what motivates continued efforts aimed at its improvement.

In 2017 the EU-ETS covered 40% of the total European GHG emissions, and its implementation was planned to happen in four phases. The first two phases were characterized by carbon prices instability and market imbalances in terms of available allowances and verified emissions. The lack of accurate data in the period pre-EU-ETS and the 2008 economic crises are amongst the most contributing factors for such undesirable scenario, even though the emissions covered by the scheme had a consistent decrease trend in the period.

In order to address such scheme inconsistencies, the European Comission featured important design improvements such as the back-loading measure, the cap and annual linear reduction factor review, the scope extension, the restriction on international credits utilization, the implementation of discretionary carbon price management mechanisms, and the allowances allocation process review.

The back-loading measure application and the market stability reserve (MSR) implementation were not effective in addressing the structural surplus of allowances banked forward from phase 2 and still persistent in the last years of phase 3. As a consequence, carbon prices remained in low levels and were unable to consistently drive industry investments towards green process and technologies.

Besides the lack of accurate emissions information during the pilot phase and the unforeseen economic crises during phase two, it is not clear why the EU-ETS was not able to properly address the

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persistent structural market imbalance, but there are studies indicating that the lack of proper assessment on environmental policies overlapping effects should be included as one of the reasons why the scheme performance is not as expected.

A combination of factors positively impacted the carbon market by the end of the current phase 3. The featured improvements combined with the adjustments planned for phase 4 motivated market speculation on the increasing need for permits to cope with ascending industrial output levels. As a result, EUA prices increased from €5.52/tCO2 in January 2017 to €24.10/tCO2 in December 2018. However, the emissions figures for 2018 are yet to be published, thus it is not possible to assess how the carbon price recent upward movement impacted the EU-ETS emissions trend.

The flaws observed in the EU-ETS allowances allocation process also caused some relevant economic issues. The over allocation of permits allowed companies to gain windfall profits by passing through to consumers the carbon allowances costs, even for permits earned for free. And such windfall profits were raised by the practice of surrendering the cheaper international permits issued by the CDM project. Consequentially the allowance allocation process did not fulfill its expected purpose of assuring a lesser impact on trade and competitiveness. Instead, it transferred customer income to the industries segments and impeded the strengthening of the European resources aimed at fostering greener technologies.

Finally, notwithstanding the planned EU-ETS design evolution and the accompanying policy improvements as regards to the Effort Sharing Decision (ESD), the Renewable Energy Directive (RED) and Energy Efficiency Directive (EED), the EU member States' projections converge to an EU-wide total GHG emissions reduction of at most 32%, which falls short of the 40% target for 2030. EU-ETS specific projections indicate that the stationary installations could reach a 10% reduction on emissions between 2020-2030, which is insufficient for the accomplishment of the 2030 reduction target of 43% compared to 2005 levels.

Therefore the achievement of the EU ambitious targets will require additional policies resulting from new holistic and creative approaches targeting carbon emissions trends prediction and efficient allowances allocation processes. And as such, the information compiled in this chapter was accrued from the analysis of the most important European environmental official reports issued during the last ten years, and may support further studies targeting the improvement of emissions trading schemes' designs worldwide. More specifically, research groups working on the development of environmentally driven market mechanisms would find here detailed considerations on attempted financial strategies, experimented carbon schemes parameters and carbon allowances prices behavior as observed in the most important and comprehensive ETS ever implemented.

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Chapter 10
Electric Car-Sharing as a Solution Supporting the Development of Electromobility and an Element of the Travel Chain

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ABSTRACT

The recently observed increase in the number of car-sharing operators using a fleet of electric vehicles created an opportunity to expand existing ecological travel chains. Electromobility is one of travelling options that reduces the transport carbon footprint. The goal of the chapter is to draw attention to the need of using car-sharing to promote environmentally friendly behavior and overcome concerns related to using an electric vehicle. The work presents the development of electric car-sharing in Europe and indicates challenges for further expansion of electromobility. By adding electric-car-sharing to the travel chain, the perception of ecological travelling significantly changes, since it combines various advantages for the user (e.g., comfort of travelling and individual trip) and a positive effect of such a choice on the environment and the city.

INTRODUCTION

Sustainable transport development is a challenge for today's cities. It is often difficult to convince people who travel using environmentally friendly modes, such as public transport, cycling or walking (among others Banister (2008), Gärling and Fujii (2009), Ruiz et al. (2018), Sierpiński et al. (2016). Although, in recent

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years, electromobility has been added to the group of pro-ecological solutions (Federal Ministry for Economic Cooperation and Development (2016), Cansino et al. (2018), the increase in the share of electric cars in relation to conventional vehicles is still too slow. It results from the lack of sufficient trust in new solutions (Czech et al., 2018). Other reasons include major barriers in selected countries, such as a high price of an electric car or poorly developed infrastructure (low number of charging stations) (Kubik, 2018; Turoń et al., 2018).

It should be noted that considering organizational solutions there is a chance to change the situation. Car-sharing enables to rent a vehicle temporarily (Turoń & Czech, 2019). The solution itself some features that can be appreciated by the city (Awasthi et al., 2009). It limits the number of cars in the road network in a given area during the day and reduces space occupied by vehicles (Luan, 2018). At the same time, car-sharing can be an element of the travel chain. A traveling person, knowing that she/he can use the car-sharing service in the destination city, will more likely choose public transport (e.g. railway or coach connections) to travel to the city.

Bearing in mind the above, the use of the fleet of electric vehicles in the car-sharing service allows, on the one hand, to maintain the positive features of the service itself, and on the other hand, it is an important way of promoting electromobility in the city (among others Dijk et al., 2013), Mounce et al. (2019). Thus, we can much faster overcome barriers resulting from the lack of knowledge among people traveling as regards the use of electric cars. Moreover, the implementation of electric car-sharing also forces faster development of infrastructure and building a larger number of charging stations.

Decision making regarding the sustainable travel chain can be supported by modern technologies. The purpose of the chapter is to present challenges faced by modern cities, which are related to the development of electromobility. As the first step, electric car-sharing may be implement and develop. Selected research in the area have been funded by the National Centre for Research and Development as a part of the international project under the ERA-NET CoFund Electric Mobility Europe Programme "Electric travelling - platform to support the implementation of electromobility in Smart Cities based on ICT applications" (Project Proposal, 2016).

E-CAR-SHARING, OR CLASSIC CAR-SHARING WITH A FLEET OF ELECTRIC VEHICLES: CHARACTERISTICS, CLASSIFICATION, AND MARKET'S PRACTICES

The development of various forms of urban mobility designed to reduce negative impact of traffic on the natural environment has become a major focus of the European Union in the context of "green transport" and "clean energy" ("Clean Power for Transport: A European alternative fuels strategy", COM (2013). The promotion of transport using alternative energy sources fits very well into this trend. Currently, a particularly strong emphasis is put on mobility services based on the use of electric vehicles ("Online Platforms and the Digital Single Market, Opportunities and Challenges for Europe", COM 208 (2016). From the point of view of an individual user, electromobility is costly. Apart from a significant cost, it still struggles against limited availability to infrastructure dedicated to electric vehicles (Sierpiński, 2018; Turoń, 2018; Turoń & Sierpiński, 2018; Turoń et al., 2018) and reluctance of users to a new technology (Carleton (2016). A solution to the above is to offer such transport services to the public. It includes, for example, ride-sourcing based on the use of electric vehicles (e.g. Uber), e-hailing (e.g. Taxify) or electric car-sharing. From the point of view of the user and her/his experience with electromobility, car-sharing provides the largest possibilities to drive and short-term use of electric vehicles.

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Car-sharing, which is a form of modern mobility, includes services based on the short-term rental of vehicles in a city with the goal of eliminating the need to use one's own vehicle (Britton, 2000). First such systems in the world used conventional cars and they were established on the market in 1948 (Muheim and Reinhardt (1998). At that time, the vehicle rental system was stationary, i.e. round-trip (vehicle was rented and returned in exactly the same location) (Ciari et al., 2014), Ferrero et al. (2018). Over the years, systems evolved providing an option to rent a vehicle in one place and return it in another indicated by the operator - the so-called base system (Awasthi et al. (2007), Ciari et al. (2014), Ferrero F. et al. (2018). Currently, the most common form of car-sharing is to rent a vehicle from any place within the operator's area and leave it in freely chosen location within that area - the so-called free floating system (Nourinejad and Roorda (2015), Shaheen et al. (2015)).

In the case of electric car-sharing or e-car-sharing, we refer to a vehicle rental system in which vehicles with electric drive are available to customers (Turoń & Sierpiński, 2018).

Therefore, in addition to the classic division of car-sharing systems due to the area of operation or business type (Ciari et al., 2014; Münzel et al., 2017), authors proposed classifications characteristic for car-sharing systems using electric vehicles, giving examples of individual business solutions used depending on the solution.

1. Electric Car-Sharing in the Case of Car Fleet

Car-sharing systems have not changed with the introduction of the electric vehicle fleet and, according to the trend, free-floating prevails in electric car-sharing. Main differences are related to: fleet type and charging of vehicles.

the first of the divisions of electric car-sharing systems, according to the authors, should be based on the type of car fleet used in the systems. Due to the existing fleet of vehicles, currently two main types of electric car-sharing systems can be distinguished on the market (Mindur et al., 2018)

- With a fully electric fleet of vehicles,
- With a fleet of electric vehicles supporting the main fleet of electric vehicles.

In the case of Poland, the first car-sharing system that operated a fleet of electric vehicles was established in 2017 (Vozilla Car-sharing system's operator website, 2019).

In turn, an example of an enterprise that owns only a few fully electric vehicles is, for example, Pony Car-sharing operating in Bucharest, Romania. The company has introduced the BMW i3 electric vehicles to the fleet of classic cars such as Smart ForTwo and Mini One (Pony car-sharing system's operator website (2019).

2. Electric Car-Sharing in the Case of Vehicles Charging

In this case, we deal with the two main types of vehicle charging in e-car-sharing, where:

- Charging of vehicles is the sole responsibility of the system operator,
- Both the system operator and users can charge electric vehicles.

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In the case of e-car-sharing, it is the infrastructure for charging electric vehicles that plays the largest and the most difficult role. It should also be mentioned here that car-sharing companies own charging stations or use public charging stations. Another Polish example of an enterprise based solely on electric cars is GreenGoo (GreenGoo car-sharing system's operator website, 2019). The operator began operating on the market in December 2018. This is a special case of the e-shared mobility service operator due to the fact that in addition to the electric vehicle fleet, the company also has its own infrastructure for charging electric vehicles, which gives it strong energy autonomy in relation to other operators operating on the market (GreenGoo car-sharing system's operator website, 2019). A similar solution on the European market is, for example, ZenCar offering fully electric Renault Zoe operating in Brussels in Belgium (ZenCar car-sharing system's operator website, 2019).

3. Electric Car-Sharing in the Case of Business Model of the Company

Depending on the system, two main types of system functioning can be distinguished in terms of the business model:

- Pilot model,
- Classic model (permanent).

In the case of pilot models, you can talk about systems that have been launched on the so-called "test" to check if the service will be adopted in the society and local environment.

There are usually several rental cars for customers in pilot projects. An example of this is the pilot project launched by SEAT automotive company in Barcelona in July 2018 (SEAT pilot car-sharing project, 2018).

The other example is Polish Innogy program, which took place in Warsaw from February to April 2018 based on 6 electric cars (Innogy car-sharing system operator website, 2019). During the project, 1.6 thousand users have driven 15,000 kilometres by car (Innogy car-sharing operator summary, 2018). The pilot project carried out resulted in the launch of the InnogyGo system! in April 2019 with a fully electric fleet of vehicles in the amount of 250 units (Wysokie Napięcie Portal, 2019).

In addition, due to the business model, we can also distinguish companies operating globally with representations in individual countries, eg Car2Go / DriveNow (Car2Go Blog (2018), DriveNow blog (2018).

In addition to the above-mentioned divisions, e-car-sharing can be also divided in order to the relationship between the operator, customers and enterprises (Turoń and Czech (2019). The standard three divisions can be distinguished:

- **B2C (Business-to-Consumer)**: Classic relation of providing vehicles to clients by operators.
- **B2B (Business-to-Business):** The relationship of providing vehicles for enterprises.
- **P2P (Peer-to-Peer)**: Providing own vehicles to individual users through various platforms.
- **NFP (Non-Profit or Co-Operate)**: providing vehicles in systems without profit or in partnership with local governments.

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Examples of business systems are all kinds of large enterprises operating for profit. They are such operators as Emov or Traficar (Emov car-sharing operator system website, 2019), Traficar car-sharing operator system website (2019).

In turn, the example of car-sharing where vehicles are offered not to individual clients and organized enterprises is, for example, Ubeeqo (2019). Then, the kind of car-sharing is called corporate-car-sharing. In a peer-to-peer system, individual users share their cars for minutes. The solution is, among others, the Getround platform operating in the United States (Getround platform, 2019).

The example of the electric car-sharing system that works in cooperation with the city is the Polish company Vozilla cooperating with the city of Wrocław (Vozilla car-sharing system operator website, 2019).

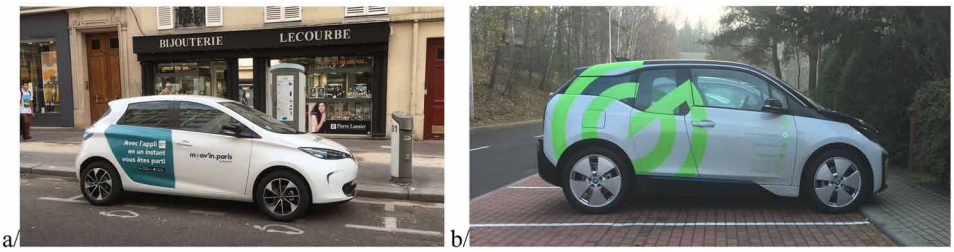
E-CAR-SHARING MARKET DEVELOPMENT

Currently, car-sharing systems based on a fleet of electric vehicles have become increasingly popular. Based on the research covering 46 European countries, e-car-sharing systems have been found in 29 of them, which accounts for 63% of countries surveyed in Europe. Those systems started in 2011, but a considerable increase in the availability of electric vehicles was observed in 2014-2016. The largest interest, however, was noted last year (2018). The growth can mark a significant development of electromobility policy in European countries. The development of electric car-sharing based on the example of selected European systems is presented in Table 1. Figure 1 includes an example of electric vehicles used in car-sharing operator fleets.

The examples presented above indicate the achievements that have been implemented in companies in the field of electric mobility. In 2018 the electric car-sharing services rapidly developed with 4 new systems launched on the market. Currently, in 2019, two more operators introduced a fleet of electric vehicles to the market. Other consecutive projects are expected to follow.

According to the table, based on the analysis of 29 systems, it was possible to determine the development of e-car-sharing in Europe (Figure 2).

Figure 1. Examples of electrical vehicles in car-sharing: a/ Renault Zoe, Moov'in (Paris); b/ BMW i3, GreenGoo (Katowice)
Source: own research



a/ b/

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Table 1. Examples of car-sharing systems introducing electric vehicles in Europe in recent years

Implementation year	Country	System's name	Fleet size
2008	Norway	MoveAbout	70
2011	France	Autolib'	3980
2011	The Netherlands	Car2Go	350
2016	Romania	Pony car-sharing	100
2016	Denmark	GreenMobility	400
2016	Spain	Emov	500
2016	Monaco	MoBee	15
2016	Luxemburg	Carloh	3
2016	Croatia	SpinCity	10
2016	Belgium	Zencar	48
2017	Poland	Vozilla	200
2017	Poland	4Mobility	2
2017	Estonia	Elmo Rent	30
2017	Spain	Zity	500
2017	Russia	YouDrive	7
2018	Poland	Innogy	6
2018	Poland	Traficar	9
2018	Poland	GreenGoo	14
2018	Poland	eCar Tauron	20
2018	Poland	Panek	10
2018	Poland	PGE car-sharing	5
2018	Bulgaria	Spark	25
2018	Czech Republic	Car4Way	15
2018	Romania	BCR Ego	20
2018	Ireland	GoCar	50
2018	Portugal	Emov	150
2018	Hungary	MOL Limo	300
2018	Sweden	Aimo	300
2018	France	Moov'in.	120

Source: Based On Car-Sharing Operators (Moveabout, Autolib', Car2go, Pony Car-Sharing, Greenmobility, Emov, Mobee, Carloh, Spincity, Zencar, Vozilla, 4mobility, Elmo Rent, Zity, Youdrive, Traficar, Greengoo, Ecar Tauron, Panek Car-Sharing Pge Car-Sharing, Spark, Car4way, Bcr Ego, Emov, Mol Limo, Aimo, Moove'in) Websites (2019) Presented In References)

INTEGRATED TRAVEL CHAINS SUPPLEMENTED BY E-CAR-SHARING

The supply chain can take different forms and follow different approaches in the design and optimization (Grzybowska et al., 2014; Awasthi, et al., 2014; Grzybowska & Kovacs, 2017). Regarding trips made, from the point of view of the city, the least efficient form of travelling is the use of an individual car for inbound trips (non-stop). Globally, a large number of cars in the inbound traffic occupy large

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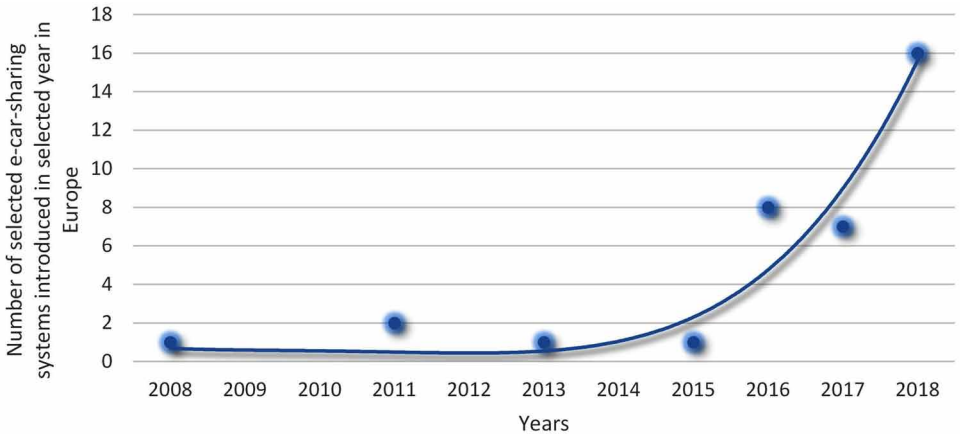
Figure 2 Development of e-car-sharing systems in Europe
Source: based on Car-sharing operators (MoveAbout, Autolib', Car2Go, Pony car-sharing, GreenMobility, Emov, MoBee, Carloh, SpinCity, Zencar, Vozilla, 4Mobility, Elmo Rent, Zity, YouDrive, Traficar, GreenGoo, eCar Tauron, Panek car-sharing PGE car-sharing, Spark, Car4Way, BCR Ego, Emov, MOL Limo, Aimo, Moove'in) websites (2019) mentioned in references



urban space (Stanley, 2014), significantly impede the development of other forms of travelling (taking over space from pedestrians or space otherwise designated for construction of cycling paths etc.). This reveals a conflict of interests, since the most convenient way of travelling is to use one's own vehicle (Montgomery, 2013). The travel chain may be juxtaposed with two types of travelling:

- Trip within a specific urban area (city, metropolis etc.),
- Trip between the outskirts and a specific urban area.

In both instances, the City, while implementing various organizational solutions and investments, offers more environmentally-friendly solutions to travellers, such as public transport (bus, tramway, trolley bus, underground etc.), use of one's own bicycle to travel along dedicated lanes, use of city bike systems or travelling by foot along properly organized and secure pedestrian infrastructure (Jacyna et al., 2013; Okraszewska et al., 2018).

It is easier to convince people travelling within a particular urban zone to use alternative forms of travelling due to a small distance between their origin and destination. In such cases, the travel chain may be simplified: a walk to the means of public transport or a city bike rental, then travel to a stop or a docking station located as close to the destination as possible, and a walk to the destination. Sometimes, in the case of longer trips, but still within the zone, there may be a need to transfer between several means of public transport.

Yet another example involves a trip between the urban zone and its surrounding. Then, the travel chain is usually more elaborate (Figure 3). The access to the urban area is possible by means of transport used on long distances, such as an airplane, train, or a passenger car (Reichert & Holz-Rau, 2015). Connecting particular trips into travel chains, while reducing the negative impact of transport on the urban zone, requires the City to identify locations where people need to transfer to a different means of transport (Figure 4). These are respectively:

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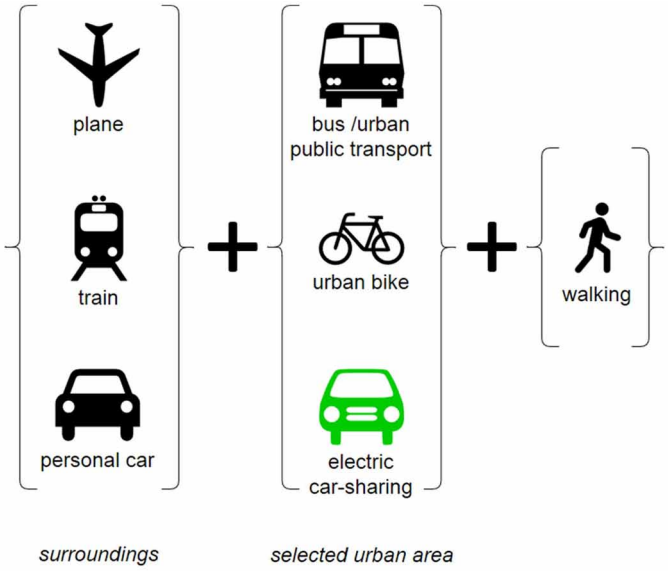
Figure 3. Examples of sustainable travel chains between the surrounding and the urban area, which include e-car-sharing
Source: own research



- Airport, usually located outside the city or on its border (Merkisz-Guranowska et al., 2016)
- Railway station, often located in the centre of the urban area and in the form
- Of structure on the site or underground (The Swedish Transport Administration, 2018)
- Car parks, which should enable to park the car and continue travelling using more environmentally friendly modes of transport. Park & Ride systems should be located at the boundary of the urban area (Holguin-Veras et al., 2012; Clayton et al., 2014; Song et al., 2017), but there are also exceptions to that (Sierpiński et al., 2019). Creating dedicated parking places for car-sharing vehicles (Kostrzewski & Varjan, 2018), could be another type of incentive which help potential user to make proper choose of travel chain.

The development of electromobility has also reached car-sharing (Shaheen et al. (1999). Thus, on top of the organizational advantages of the solution, namely reduced space occupied by cars (several people can use one vehicle during one day), we have an additional advantage of reducing the transport carbon footprint due to the use of alternative energy source. Such an electric car-sharing may also become a part of ecological travel chains (Figure 2). By creating dedicated parking places for car-sharing vehicles, as well as charging infrastructure in the vicinity of the main train stations, transfer points and airports (Ai N. et al. (2018), e-car-sharing has a chance to be the means of transport of user's choice as a component of their itineraries. This is particularly important in the case of travelling between the outskirts and the urban zone. This alternative to other modes combines advantages of a passenger car (which is important for supporters of this form of travelling) and ecology (which in turn is important for the City).

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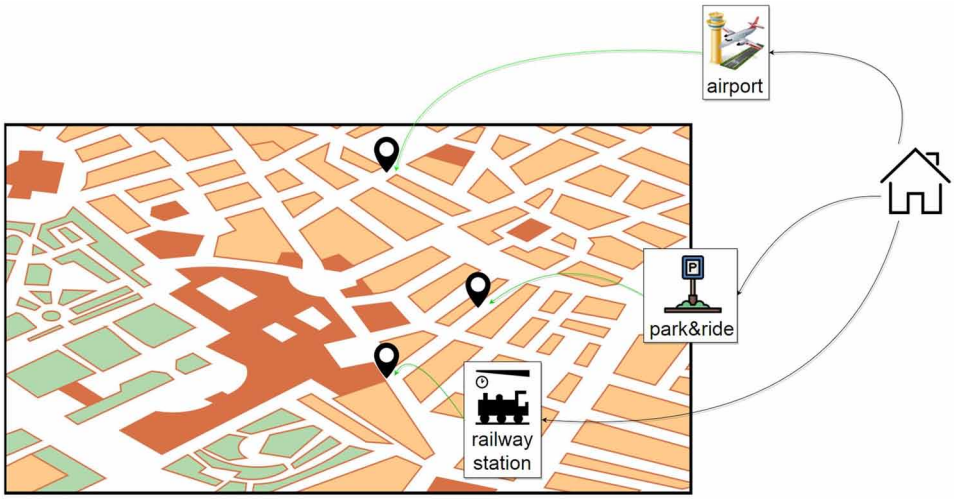
Figure 4. Location of transfer points in the travel chain (changing means of transport) in urban area and its surrounding
Source: own research



CHALLENGES FOR THE DEVELOPMENT OF E-CAR-SHARING AND ELECTROMOBILITY IN CITIES

Both implementation and subsequent maintenance of efficient e-car-sharing systems pose a number of challenges to system operators and cities. Some of those challenges faced by cities while implementing electromobility include insufficient electric vehicle charging infrastructure (Turoń & Sierpiński, 2018). One of possibilities to increase the number of charging points in the city is to sign a contract with the car-sharing operator who, apart from providing the fleet of vehicles, develops charging infrastructure.

Another challenge is the lack of appropriate education of the public about electromobility and the need to show people possibilities of using electric vehicles while travelling (Turoń et al., 2018). Special attention should be given to various concerns associated with insufficient technical knowledge about the use of such vehicles or no previous experience with the new technology (Turoń et al., 2018). In this particular case, car-sharing can also provide educational role by ensuring the availability of electric vehicles at relatively low cost for the user comparing to the purchase of an electric car.

Another challenge in the process of turning your trips into ecological chains and optimizing of the travelling in the city is the provision of relevant information. The mere set up of alternative forms of travelling, without the above-mentioned education and information, does not produce desired results. A person travelling, both within the urban zone and arriving from the surrounding area, should be able to access all modes and compare their parameters. The main criteria include time and distance (Jaunzems & Lektauers, 2013; Borkowski, 2017). Competent information following the principles of sustainable development should also contain other data, i.e. a comparative summary of particular modes and their impact on the environment (Sierpiński, 2017).

Cities operate multiple passenger information systems and public transport is supported by an independent information system, while the e-car-sharing has dedicated mobile applications that provide information to users about current position of vehicles. The idea of having integrated travel chains en-

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compasses the aggregation of data in one trip planner and takes into account current information about the transport system. For this reason, the trip planner should include ITS data regarding congestion and also the fleet of electric vehicles available in the city (Sierpiński & Staniek, 2018).

CONCLUSION AND FUTURE RESEARCH DIRECTIONS

The work presents various examples of electrical car-sharing due to fleet, loading, location and business model criteria. The chapter refers to dozens of examples of global car-sharing systems. The presented material is a form of managerial research study, which is a business understanding of the e-mobility market.

The concept of green travel chains becomes particularly important in the case of cities that want to reduce the negative impact of transport on the environment. The chapter can be summarised by highlighting a number of important steps (Figure 5) toward the integration of various modes (including electromobility): These are respectively:

- defining of the urban zone (limited spatial zone should be tuned with current city and regional development strategy, which can ultimately cover the whole city or its part),
- identifying of available green travelling modes in the city (including e-car-sharing operators),
- improving of the transport system within the zone (including number and location of charging points and public transport routes, and transfer locations),
- disseminating of knowledge and information about electromobility and sustainable development (this can be done in parallel with introduction of incentives for users
- who use ecological transport chains, and restrictions in relation to traditional travelling by car (Meyer, 1999; Choocharukul et al., 2008; Sierpiński et al., 2015; Szarata et al., 2017),
- initiating of the operation of a trip planning system which takes into account all available modes of travelling and current ITS data.

In most cases city centre is the area to implement integration solutions. That is why borders of the area should be take into account as places to locate transfer points, Park&Ride systems etc. Available green travelling modes in the city strongly depend on current level of sustainable transport development on the area. According to electromobility development research works should be realize in direction to renewable energy and smart grid (Lemon & Miller, 2013). It is individual problem for each area, but in long term it may help to implement electromobility faster.

According to disseminating step - simulation models can be used for verification of e-car sharing distribution processes (among others Fassi et al., 2012; Grzybowska & Kostrzewski, 2016; Bischoff & Maciejewski, 2016; Kostrzewski, 2017; Pijoan, 2018).

These activities, which have been carried out to a certain extent by the project of "Electric travelling", are designed to achieve the following long-term goals:

- Increase the number of charging points in urban and suburban areas,
- Increase the number of electric vehicle users (by overcoming barriers related to perception of electric vehicles from point of view of limited range, poor infrastructure etc.),

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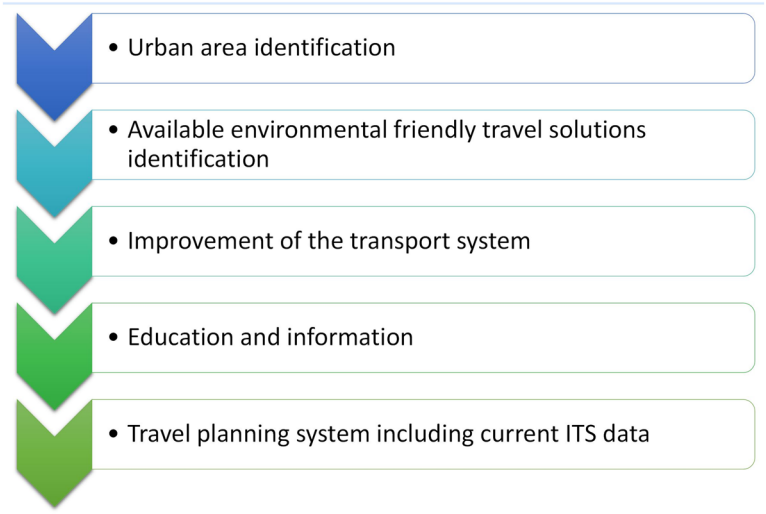
Figure 5. Consecutive steps towards trip integration within ecological chains
Source: own research



- Increase the number of people aware of the transport carbon footprint, and change their travelling behaviour towards more environmentally friendly solutions (enhanced social acceptance of electromobility),
- Reduced pollution and noise in urban areas,
- Improved integration of existing transport systems in cities.

At the end should be mentioned that building an adequate level of integration of travel chains is a complicated and long-lasting process (Fulton et al., 2017). The city lives its own life and changes are difficult to predict. Many of existing solutions can be used to help people with travelling in a environmentally way. However electric car-sharing systems are very flexible. Cities should search for that kind of support to make faster full implementation of electromobility and this should be also further research. One of the answer may be also comparison of different strategies in implementing green travelling policy. What more, unpredicted solutions connected to the subject matter could be generated with use of design thinking method (Kostrzewski, 2018).

Figure 6.

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KEY TERMS AND DEFINITIONS

Car-Sharing: Carsharing, car sharing (in AU, NZ, CA, TH, US), or car clubs (in: UK) is a model of short-time car rental where people rent cars often by the minutes. Cars-sharing gives the opportunity to drive individual car without owning it. Carsharing is part of shared mobility concept. Carsharing enables an occasional use of a vehicle or access to different brands and models of vehicles – from small urban cars to vans and premium vehicles. The renting organization may be a commercial business. Users can also organize as a company, public agency, cooperative or grouping with using internet platforms.

E-Car-Sharing: The concept of car-sharing based on using electric vehicles in the car fleet.

Electric Vehicle: EV; the vehicle (i.e., electric bicycle, electric scooter, electric car, tram, electric bus, trolleybus, electric train) having one or more electric motors as a drive.

Electromobility: Electro-mobility; general issues regarding the planning, implementation and use of electric vehicles. This term refers to the technical as well as operational aspects of electric vehicles, technologies and charging infrastructure. The term also applies to social, economic and legal issues related to the design, production, purchase and use of electric vehicles.

ICT: Acronym from information and communication technologies; concept covering technologies that process, collect and transmit information in electronic form.

Intelligent Transport Systems (ITS): An information and communication system aimed at providing services related to different types of transport and traffic management, allowing better information to different users and ensuring safer, more coordinated and "smarter" use of transport networks. Such a system combines electronics, telecommunications and information technology with transport engineering to plan, design, operate, maintain, and manage transport system.

Mobility: Mobility (incl. transport mobility, urban mobility), so-called communication behaviors that define as a whole of views, opinions and convictions related to the intention of overcoming space. In order to meet communication needs, many options are available for all types of travel purposes, taking into account different motivations, such as: travelling to work, for educational purposes, for recreational purposes, etc.

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New Mobility: New, intelligent mobility combines classical mobility with the use of so-called modern technologies, mainly the benefits of the Internet and the use of mobile devices such as smartphones.

Public Transport: Publicly available regular transport of people carried out at specific intervals (public transport schedule) and on a specified line or transport network.

Ride-Sourcing: It is an ongoing arrangement where: the driver make a car available for public hire for passengers. a passenger uses a website or app provided by a third party (facilitator) to request a ride, for example Uber, GoCatch, and others.

Shared Economy: Social and economic phenomenon, consisting in a fundamental change of organizational and distribution models going towards dispersed networks of interconnected individuals and communities, covering both the direct provision of services by people as well as sharing, co-creation, co-buying, etc., enabling a radical increase in the efficiency of use resources.

Shared Mobility: Shared mobility refers to the shared used of a vehicle, bicycle, scooter or other transportation mode. It is a transportation strategy that allows users to access transportation services on an as-needed basis.

Sustainable Transport/Sustainable Transport Development: Refers to the broad subject of transport that is sustainable in the senses of social, environmental and climate impacts. Components for evaluating sustainability include the particular vehicles used for road, water or air transport; the source of energy; and the infrastructure used to accommodate the transport (roads, railways, airways, waterways, canals and terminals). Transport operations and logistics as well as transit-oriented development are also involved in evaluation. Transportation sustainability is largely being measured by transportation system effectiveness and efficiency as well as the environmental and climate impacts of the system.

Transport: The movement of humans, animals and goods from one location to another. In other words, the action of transport is defined as a particular movement of an organism or thing from a point A to a Point B.

Travel Behavior: Defines the approach of people to travel by different means of transport and in a variety of motivations, as well as the relationship between the decisions taken, and socio-demographic factors and spatial. The choices made are based, among others, on current capabilities, limitations, and habits.

Travel Chain: The sum of travels made on a given day. Travel chain is usually closed, assuming that the destination of the last travel is the origin of the first one. Various means of transport can be used in the travel chain.

Travel Motivation: Determine the destination by using the needs, not spatially (among others work, education, shopping, culture, etc.).

Urban Zone: Selected fragment of the area, characterized by a specific level of urbanization (among others, higher level of population, and industrial areas), having the most often organized form of public transport and a dense transport network.

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Section 2
Quality Management

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Chapter 11
Managing Cost of Quality in Supply Chains:
Arctic North Inc., Montreal Case Study

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ABSTRACT

The purpose of this case study is to analyze the cost of quality (COQ) in the supply chain process at Arctic North Inc., one of the winter jackets manufacturers in Montreal, Canada. In addition to the case study, some proposed solutions and recommendations will be chosen based on the studied performance of the company. Over the past decades, quality is becoming more and more a key factor in customers' expectations. Organizations and businesses around the world are very interested in applying methodologies and techniques to reach higher quality levels since this will distinguish them from other competitors in the market. Furthermore, measuring the COQ in an organization is very important in order to be able to identify the problem of poor quality, quantify it, and analyze its causes to be able to solve it.

ORGANIZATION BACKGROUND

Not only specialized in winter jackets but also winter accessories, Arctic North products are sold throughout the globe. Arctic North brand is designed and manufactured in Canada, following a philosophy based on the design, comfort, Canadian entrepreneurship, and providing the best customer service.

INTRODUCTION

Over the past decades, quality is developing more and more where it became a critical factor in customers' expectations. Organizations and businesses around the world are very interested in applying methodologies and techniques to reach higher quality levels since this will distinguish them from other

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competitors in the market. Furthermore, measuring the COQ in an organization is very important to be able to identify the problem of poor quality, quantify it, and analyze its causes to be able to solve it.

Nowadays, companies and organizations are more and more concerned about quality in either products or services. Experts and professors in the Quality field agreed that a decent quality would lead to better financial returns, sometimes in long terms, but finally, the goal of any organization will be reached. A decent quality means reducing waste, thus decreasing costs. From that point, we can notice the relation between quality and financial returns, whereby reaching high-quality levels, we are reducing waste, then reducing cost, and everything that is saved can be considered as a profit. Moreover, quality can be defined in many ways; one of these ways is customer satisfaction. Then, we can notice that due to the high customers' expectations, and because of the competition in any specific field, organizations are caring more about the quality of their products or services. On the other hand, supply chain management is also considered as a principal key in any organization success, where good management can result in making the entire process under control, assuring good quality, and reducing errors and failures.

When talking about Quality, we should remember the importance of the cost of quality (COQ). COQ is usually dedicated to poor quality; then, it is considered the cost of preventing poor quality. This prevention cost is not a waste but an investment that will result in reaching the main organization goals that we already mentioned: high-quality levels and better financial returns.

In Canada, due to the low temperature during winter, every individual needs a winter jacket. One of the global companies that manufacture winter jackets is the Arctic North. This case study aims to analyze the cost of quality in the Arctic North Incorporation supply chain.

In this case study, firstly a brief review of the cost of quality history has been done. Besides, the two models used in COQ has been explained. After, the importance of measuring the cost of quality has also been explained.

Secondly, an overview of the supply chain process at Arctic North has been developed including product development and its importance, managing demands, and the supply chain management process with its different stages.

Thirdly, the cost of quality at Arctic North has been studied with the application of the PAF model. Also, solutions concerning different decisions or actions related to COQ has been proposed based on the stages or activities that have been found a week or in need of improvement in the different supply chain stages.

Finally, a conclusion about this case study has been conducted including the key points, and possible future work is discussed.

Literature Review on Cost of Quality

Juran (1951) was the first to develop the concept of COQ. In the first edition of his book "Juran's Quality Control Handbook," Juran mentioned the importance of measuring the COQ and how this will impact the decisions positively about the solutions that should be implemented. At first, the COQ concept was applied in manufacturing industries, especially in Japan, where the Japanese Union of Scientists and Engineers (JUSE) was attracted to his book.

In 1956, Armand Feigenbaum developed Juran's ideas and proposed the concept of "Total Quality Control," later known as "Total Quality Management" (TQM). Regarding COQ, he mentioned that the COQ is used to measure the quality control activities.

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Also, Philp Crosby talked about the COQ mentioning it as the price of non-conformance, where he stated that it is the way to measure the quality in monetary terms. Crosby believed that the high levels of quality management in an organization would result in higher savings returns. In other words, the idea that he delivered is that rework or repair costs are higher than the prevention costs paid to ensure doing things right from the first time. From this point of view, Crosby stated that "Quality is free," which was the name of his first business book in 1979. One of Crosby's 14 steps was that it is important to evaluate the cost of quality and explain its uses as a management tool (Awasthi, 2016).

Later, Harrington (1987), the IBM quality expert, talked about the cost of poor quality (COPQ) in his book "Poor Quality Costs," where he mentioned that if systems, processes, and products were perfect, COPQ would disappear. Harrington also decomposed the COPQ into the following elements:

1. Controllable COPQ: costs to ensure that customers will receive only accepted products and services.
2. Resultant COPQ: costs incurred because of the delivery of unaccepted products and services to customers.
3. Equipment COPQ: costs of the equipment used to measure and accept products and services.

PAF Model

In 1956, Feigenbaum also presented the Prevention-Appraisal-Failure (PAF) model. The PAF model can be considered one of the most successful COQ models where costs in the entire supply chain process can be divided into four categories: prevention costs, appraisal costs, internal failures costs, and external failure costs. The following table can summarize the parameters of each category in the PAF model (Wang and Chen, 2009):

Table 1. Categories' parameters in the PAF model

Prevention costs	- Quality planning - Supplier quality assurance / Supplier assessment - Quality and process engineering - Quality training - Preventive maintenance (equipment) - Product design - Market research - Customer requirements
Appraisal costs	- Acceptance testing - Inspection/Testing materials- On-site performance test / In-process inspection - Product quality audits - Supplier monitoring
Internal failures costs	- Reworking / Repair (corrective actions) - Redesign (to meet customers' expectation) - Re-inspection - Corrective maintenance - Troubleshooting
External failures costs	- Warranty Costs - Customer complaints handling - Process waste - Lost production (because of system or labor problems) - Product scrapping

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Importance of Measuring the COQ

The COQ measurement will be performed by measuring the cost of poor quality (COPQ) since it is considered the data which the analysis will be built on. After this analysis, decisions can be made concerning the improvement solutions that should be implemented and what are the appropriate resources to be used for applying these solutions. In his book "Quality Control Handbook," Juran stated that the reason for measuring the COPQ is to be able to quantify the problem. In other words, measuring the COPQ is identifying the size of the problem and where are the areas affected by that problem. This can translate the problem in terms of money, where money is the language used by top management who usually are responsible for decision making. Thus, by quantifying the problems, the developments of solutions and improvement strategies will be easier for top management where all issues are clear and ready to analyze. Therefore, the implementation of improvement strategies will result in avoiding poor quality and reducing total costs.

Reaching higher degrees of quality conformance leads to lower total quality costs. Therefore, the COQ application will result in a lower cost per functional unit of product due to the decrease in the failure costs.

In his book "The cost of Quality," Groocock explained the hypothetical relationship between price and cost, and quality. Groocock stated that the production of a product has a limited cost, this cost will rise gradually as the quality of this product improves, but a steeply cost rising will start as perfection is approached. On the other hand, the customer will be prepared to pay a reasonable price for a good quality product, but this customer will not probably agree on paying high prices for products labeled in the degree of perfection. This reality leads us to understand that losses due to poor quality or even excessively quality can happen. Therefore, it is essential for an organization to differ between both cases. The profit region for a firm is when a good quality product is costing less than its reasonable price. Then, if a product is costing more than needed for the purpose of reaching exaggerating degrees of quality, this may force the organization to enter the high-quality loss region. Thus, the cost of a good unit product should be studied carefully (Groocock, 1974).

Arctic North Supply Chain

Arctic North is a Canadian brand specialized in manufacturing winter jackets and other winter accessories. Arctic North Inc. is located in Montreal, Canada. Then, this paper studied the case of the manufacturer located in Montreal. The design of Arctic North products is also done in Canada. Arctic North is interested in reaching higher quality degrees and improving every step in the process of product manufacturing. Therefore, it is essential for the company to conduct a cost of quality study since this study can help in measuring and analyzing the current performance. Thus it will result in specifying the areas that the company should focus on. On the other hand, the cause of choosing Arctic North for the case study was that the managerial level in the company was open for innovative ideas that can help in improving all processes. Moreover, the support from the managers was an important key that helped to accomplish this study.

Figure 1 illustrates the supply chain of the Arctic North Montreal branch. It is shown in this figure that the five main materials used in manufacturing winter jackets are ordered from suppliers. Then, manufacturing winter jackets are done. After that, Arctic North, which also acts as a wholesaler, sells jackets for retailers, or directly to customers by shipping. We should note that the products sold directly to the customer who is considered as end users are ordered online.

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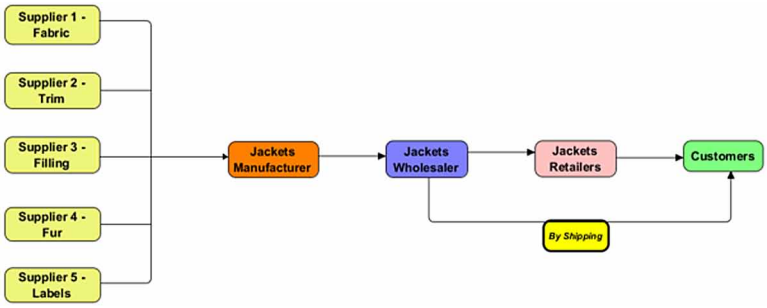
Figure 1. Arctic North supply chain



1. Product Development

Before starting with the supply chain first stage, which is ordering raw materials from suppliers, a process called "product development" should take place. The product development at Arctic North is a process done at the end of each winter season where fashion professionals from the company attend fashion shows for winter jackets to have an idea about what fashions are trending for the next winter. This step is very important in creating designs that can satisfy wholesalers and end users.

2. Importance of Product Development

Not attending fashion shows or not following the trend of the season can be considered as a risk for any company that manufactures clothes. For sure the risk directly affects the sales percentages and will result in decreasing the profits. This is due to the high impact of fashion trends on people, especially nowadays. Both television and social media are playing a significant role in affecting a high percentage of people in our society where fashion shows and the trends of the season are available to watch for everyone. Also, managers in fashion fields are using celebrities from different fields for marketing new trends. Statistics show that a high percentage of consumers will buy trending clothes even if they are not totally content with it. For example, according to Google Internal Data, searches for bomber jackets grew 612% in the United States and 297% in the United Kingdom. This can merely justify that marketing by using social media is controlling fashion trends. Then, it is significant for all clothes manufacturing companies to follow the fashion trends of the season to be able to compete with other companies and reach their financial targets.

For sure one single style or model will not fit all consumers. Because of that, fashion trends are delivering different styles or models for one type of item. This can also justify why Arctic North is manufacturing different jackets models every season for women, men, and kids.

3. Prior Standard Supply Chain Stages

First of all, we should notice that the supply chain process in some winter jackets manufactures companies like Arctic North differs a bit from other manufacturers supply chain. The reason for the difference is that winter jackets manufacturing companies should first create samples of the jackets' collection, then show this collection to the sales representatives of different wholesalers to agree on the model and

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book the required number of items for each model. Moreover, the material of jackets is subject to change if the managers found that the design can be done in a better way with another type of materials. This long time of manufacturing samples and testing them is considered as a waste for some people, but to reach customer satisfaction, or maybe to make customers delighted, manufacturing jackets to test them on reality is for the sake of the customer.

After finishing the design phase, the jackets' collection for the next winter season is ready on papers. Then it is the time of choosing the raw materials that will be used in manufacturing the different models of jackets.

4. Managing Demands

The overall demands that will be manufactured for a winter season are dived into two main processes categories: push process and pull process. This diversity of processes' types within the same company is due to having two types of customers. The first type of customers are the retailers that book their demands in advanced, and then there is a specified quantity of jackets that will be sold early before the winter season. Another type of customer is people that buy jackets online or retailers that buy jackets without prior order; in that case, the number of manufactured jackets will be decided based on estimations. Thus, based on the following two categories, Arctic North managers will decide what will be the final number of each model that will be manufactured for the next winter season:

a. Booking: Pull Process

After agreeing on the new collection, meetings are conducted with different retailers or stores representatives of winter jackets. The goal of these meetings is to make deals with the orders for the next winter season. The next step for Arctic North is to combine all bookings, ending up with the number of ordered jackets for each model.

This type of demand is under the pull process categories where the production is triggered by customer orders. In that case, the company should be flexible and ready for any variation in the demands where all bookings must be ready on time, depending on the contracts made with each store representative (Awasthi, 2016).

b. *Forecasting: Push Process*:

In addition to the booked number of jackets, the company will also forecast some jackets that will be manufactured to be sold in two different buying processes:

1- Jackets available to sell online

Arctic North is very interested in selling jackets online all over the world, especially in Canada and the United States where the company offers free shipping.

2- Jackets available to sell for retailers without booking

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Manufacturing winter jackets is a process that takes time, so new and late bookings cannot be ready for the beginning of the winter season. Because of that, a specific number of jackets will also be manufactured where it is expected to be sold for new retailers that decide on purchasing from Arctic North lately just before the winter season. In addition, a percentage of the forecast will be dedicated to retailers that come again during the winter season to purchase new jackets based on the high percentages of sales made in their stores.

The forecasted demands are under the push process category. In that case, the production is authorized based on specific estimations about the number of jackets that can be sold in the future. For the pull system, the company should use safety stock to manage the demand variability (Awasthi, 2016).

5. Supply Chain Management

After booking and forecasting, the company has the final quantity of jackets to be manufactured for each model. It is time to start running the supply chain process in the most effective and efficient possible ways in order to maximize customer values (Wang and Chen, 2009). The supply chain stages at Arctic North are described as follows:

- **Suppliers**:
- **Raw Material Demands**: The company orders all needed raw materials from different suppliers to start the production process.
- **Manufacturer**:
- **Duplicates**: The company starts to produce all items based on the models that were agreed on during collection choosing.
- **Wholesalers**:
- **Distribution**: The company distributes the products for retailers and consumers.
- **Retailers & Consumers**:
- **Products Reception**: Retailers receive their orders by specific transportation methods, then, sell it to customers. Consumers are customers that order their products online and receive their orders by shipping.

Cost of Quality at Arctic North

As we know, there are different models and techniques to measure the cost of quality. At the beginning of this case study, the PAF model and James Harrington's model was explained. If we compare these two models, we can notice that they have several points in common. The three categories of cost of poor quality (COPQ) that Harrington mentioned were: Controllable COPQ, Resultant COPQ, and Equipment COPQ. The controllable COPQ is similar to the prevention and appraisal costs in the PAF model where these types of costs are spent to ensure that the process is under control and the customer will receive the best products. The difference between Harrington's model and the PAF model is that this last can categories the costs in more detail. Concerning the resultant COPQ, this cost can be compared to the costs of the obvious failures in the PAF model where we are talking about costs spent due to failures after the delivery of the product. For the equipment COPQ type, we can notice that this type of cost can also be considered as appraisal costs in the PAF models where the goal of applying this type is to ensure that products will be inspected or tested to make decisions about either delivering it or not.

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After this comparison, we can notice that Harrington's model is probably similar to the PAF model in some areas, but Harrington was more general in dividing the categories of costs. Moreover, we cannot see that a cost related to internal failures is clearly defined in Harrington's model. Therefore, the PAF model can be considered more detailed than Harrington's model and can categories the different types of costs in a better way. Also, this categorization method will make accounting easy.

Thus, the PAF model will be applied in this case study since this model can be considered the best to fit Arctic North Inc. where it covers all the activities in the entire supply chain stages. All the costs in all supply chain stages will be distributed on the four PAF categories (prevention costs, appraisal costs, internal failures costs, and external failure costs) based on its types.

- **Prevention Costs:**

Investing in prevention is considered a critical element in a highly competitive business environment (Awasthi, 2016). The reason for this importance is that prevention can be considered the road to higher quality levels. By applying preventive actions, both internal and external failures will be reduced, knowing that the cost of preventive actions is lower the cost of failures. The prevention costs at Arctic North that can avoid failures are listed as follows:

- Planning:
  - **Scope**: Identifying the goals of the season and the processes used to reach this goal.
  - **Cost**: Estimating the budget for the season.
  - **Time**: Identifying all the activities of the season, estimating its duration, and scheduling
  - **Long-Term Decisions**: Contacting suppliers and distributors for listening to offers, to sign contracts for partnerships.
- Product Design:
  - **Product Development**: Including ideas for new jackets collection.
  - **Fashion Shows**: Attended in the purpose of validating the new fashion trends.
  - Jackets' models' design and drawings
- Suppliers Selection:
  - Negotiations about offers from suppliers concerning raw materials cost and quality.
  - Purchasing decisions about raw materials, selecting the quantity, and time to deliver.
- Preventive Maintenance of Equipment:
  - Maintenance applied to ensure the availability of all machines of equipment when needed.
  - Maintenance applied to extend the life of old equipment which is expensive to replace.
    - **Appraisal Costs:**

Appraisal costs can also be considered as an investment for the company where these costs belong to the category cots spent to ensure that the process is running as expected and the products or services will meet customers' expectations. The application of the following appraisal costs will help in controlling the entire supply chain process:

- **Supplier Monitoring**:
  - Ensuring the performance of different suppliers and controlling the process
- **Inspection**:

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    - Setup for inspection and inspection materials
    - Machines and equipment inspection to ensure the availability
- **Inventory Management**:
    - Ensuring that the inventory is ready to handle the number of raw materials under required conditions
    - Ensuring that the inventory is ready to handle the number of final products to be stocked efficiently and under required conditions
- Acceptance Testing:
    - Set up for tests and testing materials
    - Testing of delivered raw materials to decide either accepting a lot or rejecting it, taking in consideration trying to avoid producer's and consumer's risks
        - **Internal Failures Costs:**

These costs are considered as costs of poor quality. They are called "internal" failure costs since they belong to the category of costs that are found before the delivery of the product to the external customers. The cause of these costs is the non-conformance of products to the customers' expectations. The following internal failures are the main types of failures that can happen at Arctic North:

- Re-Design:
    - Corrective actions related to the product that has a high risk of not meeting the customers' requirements and expectations
- Re-inspection:
    - Re-Inspection of stocks after late defects detection
- Reworking/Repair:
    - Corrective actions related to the product that has a specific defect able to repair
- Corrective Maintenance:
    - Maintenance of machines and equipment due to failure
- Equipment Replacement:
    - Replacement of deteriorated equipment and machines with the time associated for replacement
        - **External Failures Costs:**

The external failures costs are also considered as costs of poor quality. These failures are called external since they are related to the defects found outside the company, so after delivering the product to the external customers. The external failures that can probably happen at Arctic North are as follows:

- Complaint Handling:
    - Extra time spent with customers and corrective actions due to unexpected failures
- Failure During Delivery/Shipment:
    - Products that can fail due to the wrong packaging, or items shipped under uncomfortable conditions
- Warranty:
    - Replacement or repair of inferior quality products that failed during the warranty period

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After dividing the different activities of the supply chain on the four categories of the PAF model, we can notice that if the activities mentioned in the prevention and appraisal costs will be applied, the costs of the failures will be reduced to the minimum or eliminated since it is clear that all prevention and appraisal activities can be considered as solutions for the listed internal and external failures. When the prevention and appraisal costs increase, the failure costs decrease. This happens due to the improvement in conformance resulting from applying the prevention and appraisal activities. Therefore, when conformance to specifications improves, higher quality levels will be reached.

(Wang et al., 2010) Moreover, the perfectionism area is the area where the conformance ratio is more significant than "q." The optimum level of quality is achieved when the cost is at a minimum (C_{min}) where $C_1 = C_2$, noting that the summation of C_1 and C_2 is the total cost.

When the degree of conformance is equal to "q," it means that investments in prevention and appraisal resulted in reducing the failure costs. the number of defects is less because of the manufactured products are conforming to specifications. According to the Lundvall-Juran model, when a company reaches the optimum degree of conformance, only prevention and appraisal costs are real costs, where the cost spent due to failures and defects are eliminated at that point. According to Crosby (1979) and Deming (1980), a high-quality product is cheaper than a low-quality one. Thus, it is guaranteed that if Arctic North invests in the right way in prevention and appraisal activities, the overall cost will be reduced (Patrascan, 2013).

Concerning Total Quality costs, when the quality is at the optimum level, the total quality costs are at a minimum. This translates to the stated theory of Crosby and Deming where the cost of producing a high-quality product is less than producing a low-quality product. This theory is based on the comparison between the losses due to poor quality, and the costs of improving quality where the cost spent to reach a high degree of conformance product are less than the cost spent to repair or replace a poor-quality product.

CURRENT CHALLENGES FACING THE ORGANIZATION

As a premium Canadian brand manufacturing winter jackets, Arctic North faces many challenges to deliver high-quality products, meeting customers' requirements and expectations.

The main challenge facing Arctic North is at the beginning of the supply chain process, at the raw material level. It is critical to ensure that the raw material used in the manufacturing process meets the specifications. This will eliminate the defects on the consumer level, which is considered the highest financial waste. In other words, delivering a low-quality product will result in a cost of replacement, which defines the major problem any manufacturer could face.

This problem, along with other problems like are addressed in the next paragraph.

SOLUTIONS AND RECOMMENDATIONS

After analyzing the cost of quality at Arctic North by applying the PAF model, we have now a clear vision about the current situation of the entire supply chain activities. The improvement of the process in this supply chain is crucial to result in higher quality levels reaching the long-term targets of the company. This improvement will be applied by managing all the activities from the very beginning starting from planning and ending with the delivery of the products to the customers and end users. We should note the difference between customers and end users in the Arctic North case, as already mentioned, where the

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company is selling jackets for two types of customers: the ordinary customers who are retailers, and the end users that are also customers who receive their products directly from the company. The proposed solutions will make the company stronger by grating the managerial levels from controlling the entire process and ensuring that the delivered products will fulfill the customers' requirements and expectations. Also, these solutions will decrease the risk of failures and eliminate the chance of unexpected scenarios regarding suppliers' performance, equipment failures, product failures, inventory management errors, customers' misunderstandings, inaccurate forecasting, and more. The following proposed solutions are chosen based on the case study where it is not applied or partially applied at Arctic North.

Supplier Development and Performance Measurement

The COQ for suppliers has the most significant impact on the essential PAF model category, which is the prevention cost. The supplier performance measurement is done to ensure the expectations defined in the contracts. The measurement and analysis of supplier performance can help in identifying the gaps and finding the needed solutions that can reduce these gaps. Some activities related to suppliers are described below (Awasthi, 2016).:

- **Multiple Sourcing:** This type of sourcing can be valuable in some cases where the company can guarantee that there is always a supplying source ready in case of another supplier will have a problem. Also, multiple sourcing can increase the competition between suppliers and can result in having better offers of purchasing raw materials for the company.
- **Supplier Development:** This is done by applying several activities and steps supplier evaluation and training, so the suppliers will better understand what is expected from them. Besides, sharing information and data between buyers and suppliers will make this process easier. Furthermore, the relationship between buyers and suppliers will be better.
- **Supplier Awards:** This idea can be considered as a motivation which can also increase the competition between different suppliers. The company can take the Baldridge criteria as a base for these awards.

Acceptance Sampling:

Acceptance sampling is an essential technique used to inspect the received materials from suppliers to verify that it meets the quality standards, especially when dealing with expensive raw materials.

- **100% acceptance sampling:** It is known that the fur used in winter jackets is expensive and it is considered the main reason for the high prices of these jackets generally. Then, in the case of fur or similar materials, 100% acceptance sampling is recommended to avoid high costs wastes.
- **Standard acceptance sampling:** this type of sampling can be done on a specific number of items in a lot. The number of inspected items will be specified based on the degree of sensitivity of the received materials where some materials can be damaged easily.

The sampling procedure must be accurate and errors free to avoid ending up in bad results that can be explained in the following two types of risks (Awasthi, 2016):

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- **Producer's Risk**: Rejecting a shipment of materials that have good quality.
- **Consumer's Risk**: Accepting a shipment of materials that have poor quality.

RFID Tags/Barcodes

Barcodes are used to make it easier for organizations by allowing checkout systems to read the barcode of a product, and link it automatically to the information related to that product in the database. The disadvantage of barcodes is once the information is stored; it cannot be updated. Unlike barcodes, radio-frequency identification (RFID) allows users to update or edit the stored information. This is the reason that makes barcodes a better choice in cases where the information about products is subject to change.

The usage of RFID allows Arctic North to make the process of controlling raw materials and manufactured products much more accessible. This will allow workers to be able to access all the needed information about the products like the quantity that can help in inventory management.

Data Gathering

Gathering data about transactions, actions, and activities that are happening in the supply chain can be very helpful in the future where these data can be used to result in more accurate estimations related to calculating forecasts for the upcoming season, right time for preventive maintenance, expected downtime of machines and equipment due to failure, and more.

Applying an Accurate Forecasting Method

It is known that forecasting results are not 100% guaranteed where conditions of the same products can differ from time to other. But it is also known that some forecasting methods are more accurate than others. Then, to use the best forecasting methods the company will firstly collect data about all transactions as mentioned in the previous point, then forecasting results will be more accurate which will keep the company on the safe side.

- **Forecasting Method for the Short Term:** The following short-term forecasting method can be applied at Arctic North starting from the next season since previous data is not available. This method aims to apply factor analysis by using available statistics about the current population in Canada to know the majority of the age groups and genders so that the company can build an idea about which type of jackets to manufacture more.
- **Forecasting Method for the Long Term:** The long-term method will be ready to apply after a few years of collecting the data related to the company itself. In general, forecasting is considered inaccurate, and it is recommended to be done for the near term. But for manufacturers that can never be sure about the number of products that will be sold, forecasting is needed. For Arctic North, it is suggested to use the Exponential Smoothing (with trends) forecasting method since it can be considered more accurate than other methods, or the Seasonally Adjusted Forecasts since it is based on seasonal estimations, which can help in seasonal products like winter jackets.

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Voice of the Customers

The voice of the customer means listening to customers' opinions about the product that will be delivered. This can be very helpful for an organization to build a real image of customers' desires and expectations. Involving customers should not be based only on feedbacks after delivering the product where it can be considered too late to know that the product does not meet the expectations. Then, involving the voice of the customer should be in all the process stages including the design phase particularly where it is the phase that an organization can start building a product that will satisfy its customers.

Learning customers' needs and requirements can help an organization in identifying what the clients are expecting to receive and then work on delivering a product that can fulfill all requirements so that this product can reach not only customers' satisfaction but also customers' delightedness.

Usually, in products related to clothing, the majority of people like to buy trending products, so at this point, we can feel the evidence of the importance of attending fashion shows during the product development phase.

At Arctic North, the managerial level can identify customer expectations by conducting online surveys to capture what models are the best to reach customers' satisfaction. These surveys can contain brief questions about innovative ideas for the next season collection and can include some pictures from the designed models that can guarantee that people understand what the model looks like to have accurate surveys' results.

Website Maintenance

As mentioned before in this study, Arctic North relies on a big percentage of its revenues on online sales. All online sales are achieved through the website of the company where customers can see all the models of available jackets and order it. After, the delivery of the ordered products is done by shipment. Therefore, to be able to attract customers and increase the number of online purchases, the website should always be ready for visitors. Online customers nowadays are also expecting to shop online on a new high-quality website where everything is clear, available, and easy to use. Because of that, Arctic North should invest in building a high-quality website that can reach users' satisfaction level.

Benchmarking

Benchmarking is a method for organizations that are looking forward to continual improvement. The benchmarking goal is the improvement in both organizations that are sharing information between them. Several processes and activities can be benchmarked in a company like strategic planning, process management, performance and quality levels, financials and business results, customer and market focus, etc.

- **Best-in-Class Benchmarking:** In general, small businesses look forward to applying to benchmark with the Best-in-Class organizations that are recognized as the leading organizations in the same field based on its records regarding performance, quality levels, financial returns, customer services, and other criteria.
- **Best-of-the-Best Is Benchmarking:** Another type of benchmarking is the Best-of-the-Best benchmarking where companies apply benchmarking with firms that are not from the same in-

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dustry but are considered from the leading global firms in different industries. The purpose of this type of benchmarking is to visualize the business in new and diverse ways (Awasthi, 2016).

Concerning Arctic North, it is suggested to apply to benchmark with a Best-in-Class company at this time, we're sharing information with a leading company that is better to improve both organizations. After reaching significant levels of improvement and higher levels of quality, it would be the right time to try a new type of benchmarking with a Best-of-the-Best firm.

Six Sigma Methodology

Six Sigma is one of the known methodologies used for process and quality improvement. Bill Smith introduced this methodology during his work at Motorola (American multinational telecommunications company) in 1980. DMAIC methodology, inspired by Six Sigma, includes five phases that can help to improve the manufacturing process in this study:

- **Define**: Defining the current product and process status. Gathering the customer requirements and expectations about the product (using part (6) Voice of the Customers, and survey techniques), and setting the project goal.
- **Measure:** Collecting as much data as possible about the current process, including statistics from the customer requirements defined in the Define phase.
- **Analyze:** The accuracy of data collected in the Mesure phase is very important to help to analyze the current process and product status, where areas of quality improvement can be located. Quantifiable measures are a key strength for a perfect analysis.
- **Improve:** Based on the results from the analysis phase, quality improvement is implemented to meet customer expectations. On another hand, the root cause of the entire supply chain process defects can be studied to eliminate the cost of poor quality and reduce waste.
- **Control:** Applying the improvement results from the Six Sigma study is controlled in this last phase. Control charts can be used as a tool in this phase to monitor the applied improvements, making sure the results are meeting the project goals, and the defects are eliminated.

After applying Six Sigma, along with the DMAIC methodology, the entire manufacturing process is expected to improve, leading to higher degrees of a quality product. The results of Six Sigma are also expected to increase to financial returns of the organization since eliminating defects and the cost of poor quality will lead to a business improvement, which is one of the Six Sigma methodology goals.

CASE ANALYSIS

In this section, the author provided an analysis of the case studied, including statistics and results from inspections applied on a specific winter jacket model. As mentioned previously, at the beginning of the supply chain process, inspecting raw materials is necessary to ensure that these materials are ready to use in manufacturing a high-quality product.

(Arctic North Industries) The conducted inspection will allow the quality control team to make stronger decisions on whether the material is accepted or rejected based on pre-defined specifications.

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Figure 2. St. Sauveur winter jacket

Figure 3. St. Sauveur layers

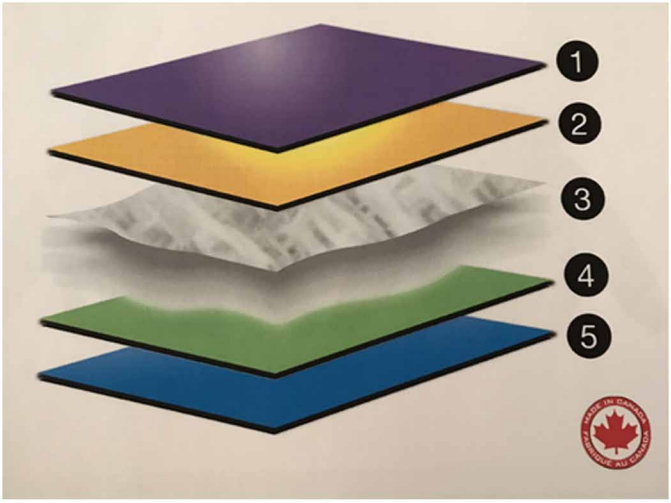

Table 2. St. Sauveur layers' description

1. Outer shell	- 85/15 Poly/Cotton (content) - 200 gsm (weight) - 15D x 21S (yarn count) - Treated for 1000 mm waterproofing, breathability, and anti-wrinkle
2. Baffle	- 100% Nylon (content) - 65 gsm (weight) - 70D x 70D (yarn count) - Treated with oil cires for down proofing. - It safely and securely contains the down filling
3. Down	- White Duck Down (90% down, 10% feather) - Highest standard washing and treatment - 625 oz/cu.inch powerfill hypoallergenic, sanitized, no odor
4. Baffle	- 100% Nylon (content) - 65 gsm (weight) - 70D x 70D (yarn count) - Treated with oil cires for down proofing.
5. Lining	- 100% Polyester (content) - 59 gsm (weight) - 50D x 50D (yarn count) - Comfortable and breathable on the inside

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The raw material inspection was conducted on a specific Arctic North jacket model: St. Sauveur.

The St. Sauveur winter jacket is popular among students and workers for day-to-day use. The jacket includes five layers.

In the following example, the author is providing a description, and inspection results on the Outershell, layer1 of the St. Sauveur winter jacket.

Firstly, a textiles quantitative chemical analysis is conducted on the jacket's first layer to make sure it meets the specifications of content: 85% Polyester, 15% Cotton. The acceptable variation is within a 5% interval [-5%;+5%].

Different test methods are used during the inspection process at Arctic North. One of the common methods is the AATCC test method. AATCC - the American Association of Textile Chemists and Colorists—is a 501 not-for-profit professional association that provides test method development, quality control materials, educational development, and networking for textile and apparel professionals throughout the world (Wikipedia).

The method used to conduct the textiles quantitative chemical analysis is AATCC 183-2014. This is a standard test method used to determine the ultraviolet radiation blocked or transmitted by textile fabrics intended to be used for UV protection. This method provides procedures for measuring this fabric property with specimens in either the dry or the wet states (American Association of Textile Chemists and Colorists).

The inspection results showed that the textile used the studied St. Sauveur winter jacket are 83.8% Polyester, 16.2% Cotton. This means that the inspection results are accepted, meeting the variation limitations.

Secondly, Color fastness inspection is conducted on the jacket. Color fastness is a term used in the textile industry to describe the resistance of fabric against color fading or color transfer. Several types of color fastness are available, the common ones are:

1. Color fastness to Washing (laundry)
2. Color fastness to Crocking/Rubbing
3. Color fastness to Light (Ultraviolet)

Color fastness to Washing, and Crocking/Rubbing are categorized from 1 to 5, the higher the number, the better the fastness.

Color fastness to Light is categorized by percentage. The higher the percentage the better fastness.

The quality control inspection results of the above types of color fastness are as follow, noting that the temperature at the inspection center is 20 degrees Celsius, and the humidity is 65.

1. Color fastness to Washing (laundry):
   Evaluates the degree of color loss after repeated home launderings.
   In real life scenarios, it is not possible to obtain results for no color fastness, so the acceptable results for Arctic North are 4 and above.
   Test name: AATCC 61-2013 1A
   Temperature: 40 degrees Celsius
   Time: 45 minutes
   Detergent: Synthetic detergent WOB 0.37%
   Steel balls: 10

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Results:
Color change 4.5
Color staining to wool 4.5
Polyester 4.5
Nylon 4.0
Cotton 4.5
Acetate 4.0

2. Color fastness to Crocking/Rubbing:
   Evaluates the degree of color transfer from one fabric onto another.
   In real life scenarios, it is not possible to obtain results for no color fastness, so the acceptable results for Arctic North are:
   4 and above in dry status
   3 and above in wet status
   Test name: AATCC 8-2016 (a Crockmeter is used in this test)
   Results:
   Dry 4.5
   Wet 4.5
   Color fastness to Light (Ultraviolet):
   The transmission of ultraviolet through materials is determined using a calibrated ultraviolet transmission analyzer.
   Test name: AATCC 183-2014
   Results:
   UV-A Transmittance (mean) 0.05%
   UV-B Transmittance (mean) 0.08%
   The results mean that the blocking of UV-A is 99.95% and the blocking of UV-B is 99.92%.

Thirdly, the quality control team conduct inspections on the down used to fill the jackets. It is important to make sure good quality of down is used which results in manufacturing warm winter jackets.

Arctic North is using duck down in winter jackets. The standard percentage of duck down in Arctic North jackets is 80%; the other 20% are Fiber, Feather, and Sediment.

The below data shows the exact percentage of the filling composition of the inspected jacket:

- Duck down: 80.26%
- Feather: 11.90%
- D Fiber: 4.41%
- F Fiber: 1.76%
- Sediment: 1.67%

In order to analyze the duck down quality, the quality control team measure the fill power of duck down received from suppliers. Fill power is the measurement of the amount of space 1 ounce of down can occupy in cubic inches. For example, 1 ounce of 800 fill power will loft 800 cubic inches. Fill power represents quality, loft, and longevity.

The higher the fill power, the larger the down clusters. The larger the down clusters, the better the isolation power, leading to a better winter jacket quality.

At Arctic North, the standard fill power is 600 per 1 ounce of down.

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SUMMARY AND CONCLUSION

In this case study, the cost of quality at Arctic North Inc., a Canadian jackets manufacturing company, has been studied. In addition, a review of the present supply chain process at the company has been developed.

Quality is considered the most potent weapon for organizations in different fields that will lead them to be able to compete with other competitors. When the quality level of a product or a service is high, customers will be definitely attracted to it. Since the primary goal of organizations is financial profits, managerial levels in these organizations should ensure that the organization quality management system conforms to customers' requirements and expectations. Being interested in reaching higher quality levels and working to improve this quality will lead to reaching the company goals.

The cost of quality is a crucial method that will help an organization to improve quality. By studying the problems and quantifying them, managers will be able to understand the problem, analyze it, and take the right decisions about the development of solutions that will be adopted to reach quality conformance.

PAF model is one effective technique where it allows users to categorize the different quality activities and actions based on their cost type. After studying each category in the model and finding the problem areas, top management will be able to decide areas where to invest in order to eliminate the poor quality costs.

In the case of Arctic North, the different stages of the supply chain process have been classified in the PAF model with a description for each activity or action. This will offer an unobstructed vision of the entire product manufacturing process. Arctic North should invest more in the prevention and appraisal sections where the different activities can result in reducing the internal and external failures. The proposed solutions are essential for Arctic North to reach higher levels of quality. These solutions are proposed to help in the cost of quality activities, and other applications that are also related to the quality field. The case analysis section showed some data and inspection results from quality control inspection conducted on a specific winter jacket model designed and manufactured at Arctic North. The main points of this section are textiles description and quantitative chemical analysis, color fastness inspection, and fill power inspection.

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Chapter 12
Quality Management in Food Packaging Industry

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ABSTRACT

Food packaging is a crucial part of our current lifestyle. It is important to improve the quality of food packaging from time to time, catering to the needs of modern consumers. Despite huge technical advancements, the food packaging sector is still facing several problems and challenges which need to be addressed, to facilitate better packaging. The purpose of this chapter is to enhance the quality of food packaging and to come up with more innovative ideas and methods based on various tools of quality. Various approaches based on new (N7) and basic (B7) tools of quality namely cause and effect diagram, inter-relationship diagram, and affinity diagram have been applied to understand and eliminate the root causes of the various problems being faced by the key supply chain players in the food packaging industry. The results of the study show that the problem does not lie in the methods or techniques applied but in perspective and inclination of the management and key players of the food packaging supply chain towards the quality.

INTRODUCTION

Packaging plays a significant role in the success of any product. Without packaging, material handling will be difficult, costlier and inefficient. Despite this utmost importance, there is no enough and up to date information about the packaging industry, its major trends and current issues which affect the packaging industry. In last 50 years, Packaging has evolved profoundly which has made our lives easier. From Heavy, rigid containers, made of wood, metals or glass, we have shifted to vast range of semi rigid or rigid and more flexible packaging materials made from specialized lightweight materials.

Consumer packaging not only ensures the security of the product by delivered the products in clean, safe form by avoiding spillage and spoilage, it delivers substantial economies and keeps the prices lower by providing the ease of handling, warehousing, retailing and distribution. With this increased advancement of consumer product goods, brand communication has become a key strategy for building

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consumer loyalty. Product packaging has become a pivotal way to communicate product values among customers. The recent key trends such as, increasing awareness of wellness health, growing concerns of environmental impact, Stronger influence of recycling and environmental issues, purchasing power, increasing incomes have enabled the development and innovation in primary packaging and has also helped in identifying the potential areas for packaging growth in all regions throughout the world. The regional and country-specific trends such as urbanization, convenience, smaller pack sizes or internet retailing, data analysis and qualitative observations often affect the global packaging industry and helps in understanding it. Other than this, macroeconomic and consumer behavior trends also play significant role in certain regions for packaging industry.

GLOBAL FOOD PACKAGING MARKET

In packaging industry, the food market has the largest consumption group. The food products need more care in terms of packaging, as it is extremely important for food packaging to be more smart, rigid and flexible than before to deliver fresh and safe products to the end consumer. Similarly, the products need to be attractive and have engaging and alluring designs to grasp the attention of the potential buyers.

The global food Packaging industry has seen significant growth in the past few years. The global food packaging market value was estimated at 282 billion US dollars in 2016.An expansion in market is being predicted over the next years, in 2016-2026. It is expected to reach approximately 306 Billion US dollars by 2019 and CAGR will showcase an increment of 3- 3.5% from 2016-2022.The revenue of the global food packaging market is mainly dominated by the USA, Germany and Asia Pacific, including countries like Japan, China, India.

Types of Packaging

Figure 1 shows the basic structure of a supply chain and associated packaging types. Mainly, packaging can be mainly classified into 3 categories. These 3 categories represent the different levels of packaging. These three categories can be used together to consider packaging as a System, with three hierarchical levels.

- **Primary Packaging (Consumer Packaging):** The package which contains the actual product is referred to as a primary package. This package is used to protect the actual commodity or material and stays with the product until it has been used by the end consumer completely.
- **Secondary Packaging (Grouped Packaging):** The layer of protection covered to the primary package is called secondary packaging. Most of the times, this package is removed and discarded once the product is ready to be used.
- **Tertiary Packaging (Transport Packaging):** Tertiary packaging helps in the identification, handling, storing and transportation of food products. This packaging is crucial and mandatory for the products, particularly the perishable products and which need to be carried away and which are loaded and unloaded many times

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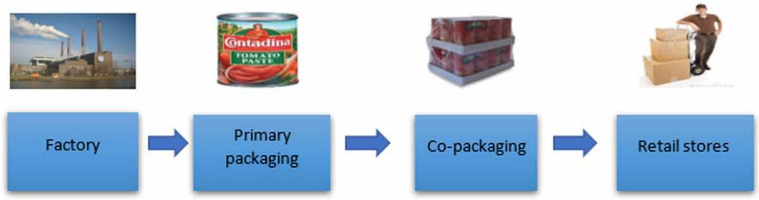
Figure 1. Packaging in the supply chain



THE SUPPLY CHAIN OF FOOD PACKAGING INDUSTRY

Figure 2 presents the detailed structure of the supply chain of the food packaging industry. Since packaging is an important interface between the supply chain and the immediate customer and end user, therefore it helps in achieving the primary task of serving the end customers. Packaging also affects supply chain effectiveness other than its fundamental function of preserving, protecting, and the product. Although, packaging has multifarious and complex functions, its definition can be mainly described with three main processes which are logistics, marketing, and environment.

LITERATURE REVIEW

Research on quality management in the food packaging industry is very limited and new. Wang et al. (2017) propose a decision-making trial and evaluation laboratory approach to analyze the barriers to Green Supply Chain Management adoption in a food packaging company. Yıldız-Geyhan, Altun-Çiftçioğlu, and Kadırgan study social life cycle assessment of different packaging waste collection system. Maqsood, Al Haddad and Mudgil (2016) study vacuum packaging as an effective strategy to retard off-odor development, microbial spoilage, protein degradation and retain the sensory quality of the camel meat. Fang et al. (2017) study active and intelligent packaging in meat industry. Paternoster (2017) et al. (2017) study the role of vibration damping and thermal insulation on the performance of beer packaging. Palombini, Cidade, and de Jacques (2017) investigate the sustainability of organic packaging and conduct a case study of Porto Alegre city (Brazil). Rossi et al. (2017) study the role of Nanotechnology for Food Packaging and Food Quality Assessment. Majid et al. (2016) and Tencati et al. (2016) study the emerging trends, novel packaging driven by the consumption of the packaged food, rising popularity of prepared meals and smaller sized food packages due to socio-economic factors like higher incomes, urbanization, lifestyles changes and consumption patterns, smaller households, preference of smaller pack size.

To researcher's knowledge, comprehensive studies on investigating quality management issues in packaging in supply chains are rare. This is the challenge; the author is addressing in this paper.

PROBLEM STATEMENT

A survey was conducted to understand the problems and challenges faced by the various actors of the supply chains namely manufacturers, retailers, and customers. Firstly, the problems faced by **manufacturers** during the packaging of the food products were identified using a survey study. A snapshot of the survey has been given in Figure 3 below.

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Figure 2. Detailed supply chain with types of packaging used

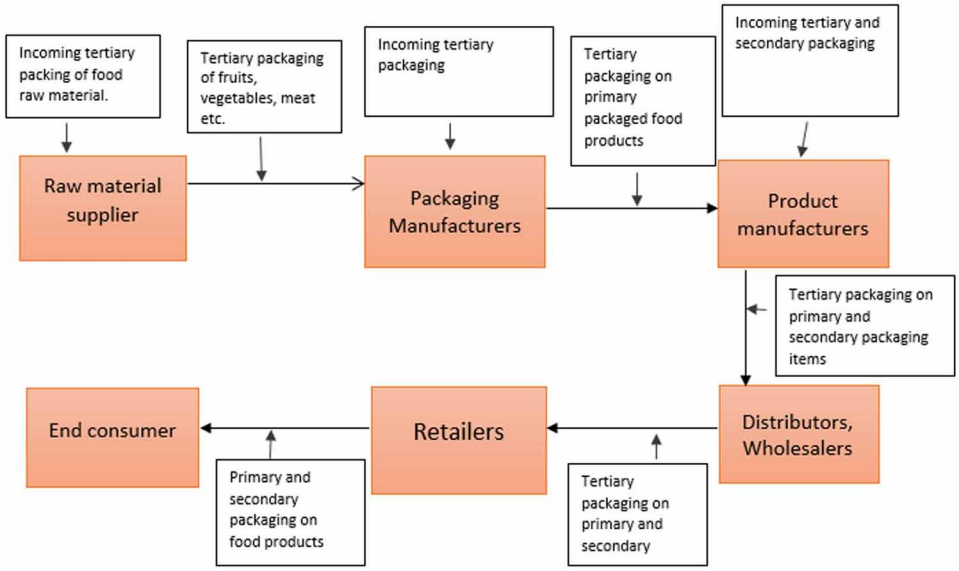
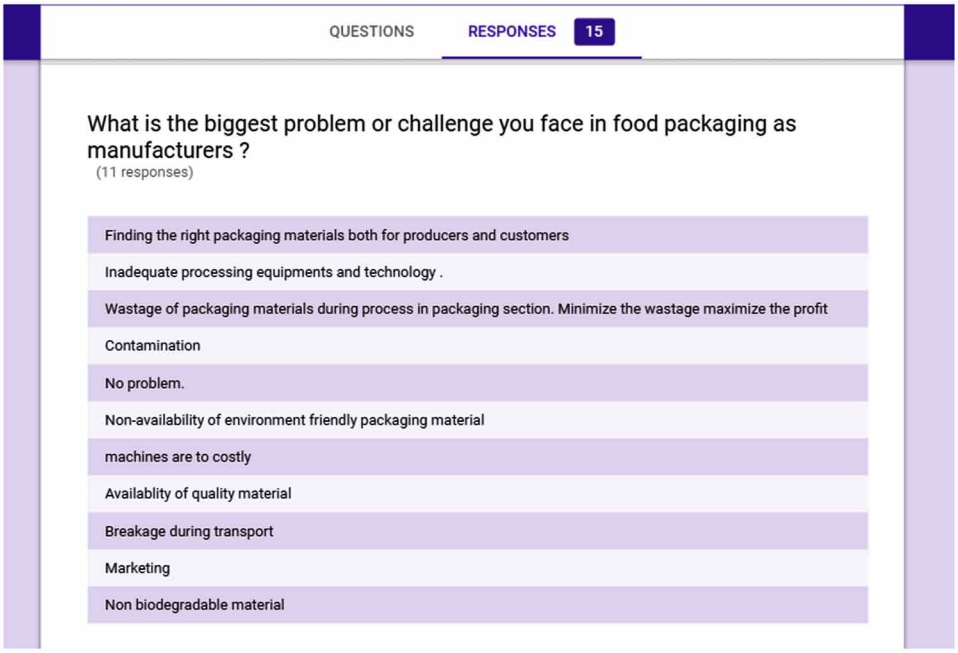


Figure 3. Responses received from survey conducted for manufacturers



15 responses were received from manufacturers from different backgrounds. 12 were considered valid and pursued further study which led to a better understanding of their problems. Following problems were reported.

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- **Finding the Right Material:** While it is easy being said, it is quite challenging for the manufacturers to find the right type of good quality packaging material which is suitable for both, the customers as well as themselves.
- **New Technology or Inadequate Processing Equipment**: To remain updated, manufacturers need to make more prototypes, test and launch more new products to oblige and accommodate more consumer trends and taste preferences. However, for small scale businesses, it is difficult to equip themselves with the latest technology. Since, Processes and technology should be used to establish more automated processing, freezing baking, canning, or packaging and producing healthy products, it poses a major challenge for some of the manufactures.
- **Contamination:** Packaging itself can be a source of contamination with the migration of substances from packaging into food. Some of the food additives added to the foods intentionally or those which end up in the food from the packaging material and processing equipment leads to the contamination. It might also occur during transportation from inappropriate or damaged packs, containers. Therefore, it is another big threat for the manufactures as well as the customers.
- **Costs:** Manufactures feel pressure from both consumers and competitors, which makes them lower their prices the costs for raw materials such as pulp, resins, films and bottles have increased which has further led to the increment of secondary and tertiary material costs. Cost issues might occur because of the wastage of material during packaging that is not meant for sale or because of breakages, damages, mishandling during manufacturing or transportation. Also, Customers expect better higher service levels but are not willing to pay for these additional services. Additionally, costs of machinery for more automation only adds to this.
- **Quality Issues:** One of the biggest challenges is to maintain the quality control over food packaging materials. For instance, many importers receive damaged goods due to inferior packing materials. These issues occur due to poor quality raw materials, human errors, inexperienced staff, formulation changes or product mix.
- **Sustainability Challenges**: To meet sustainability standards and challenges, multiple strategies are needed. Sustainable packaging focuses on design for recyclability, recycled content, weight reduction, renewable or bio-based materials compostable materials. These criteria are hard to meet while aiming for wider market, profitability, product safety, lower costs, and competitive advantage
- **Innovation:** Packaging innovation is an ongoing challenge while allowing the products to grow in a more effective and efficient way. This only adds to the increase in the costs. Further with more competition than ever and newer products, it becomes difficult to come up with innovations. The actual driver of innovation is the end-market consumer, therefore packaging producers need to have well-developed relationships with their customers.
- **Damages during the Transportation**: Damages during the transportation includes breakage of the packaged food containers, therefore leading to business losses as the customers, distributors, retailers would not accept the damaged products. Challenges and problems faced by the retailers/ distributors in the food packaging industry

To understand the challenges and problems faced by the **retailers and distributors**, another online survey (Figure 4) was conducted. Five responses were received. The survey used is shown below.

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Figure 4. Responses received from the survey conducted for retailers/ manufacturers

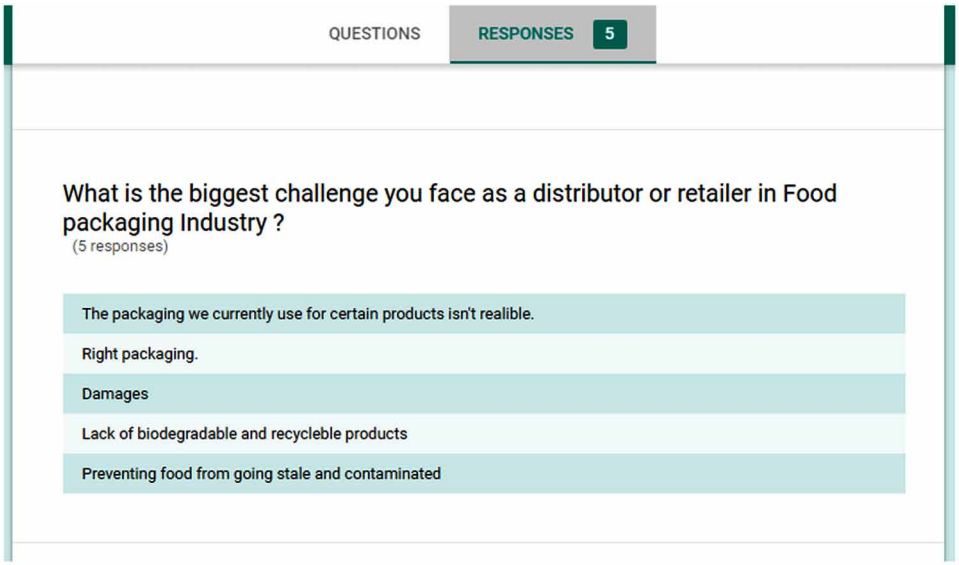
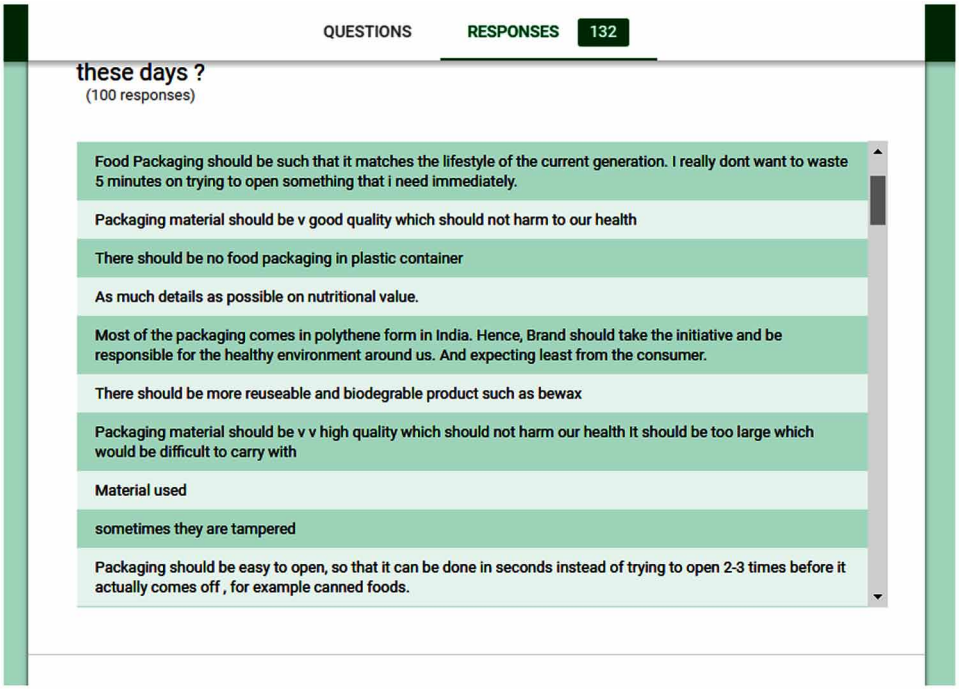


Figure 5. Responses received from survey conducted for consumers



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Following problems were reported by different retailers/distributors related to the food packaging.

- **Sustainable Packaging:** With the rapidly changing expectation of the customers with the new innovations and trends in the market, it has become difficult to live up to the expectations of the customers. Increasing customer awareness has led to increasing demands for sustainable packaging, therefore it is important for retailer, distributors, wholesalers to be continuously in touch with the producers and give their feedback, therefore encouraging and promoting sustainable packaging.
- **Breakage or Contamination:** There are always chances of selling damaged or contaminated product to the customer which might lead to bad reputation. Similarly, damages or contaminations might occur during shifting or transporting the products. This leads to delays in the meeting the demand as replacing the supplies or ordering it again will take more time, which will result in frustration or retailers and end customers both. Maintaining the food safety and keeping an eye on its shelf life is also a challenge for the retailer or distributors.
- **Unreliable or Poor-Quality Packaging**: Unreliable and Poor-Quality Packaging does not provide the expected safety and security to the products during transportation and shipments. Therefore, it might lead to damages, breakages or contamination of product during transportation, handling, thus leading to retailer's loss and reputation.
- **Right- Sized Packaging**: Finding right- sized food products according to the shelves of the stores can be a great challenge for distributors or retailers as well for an efficient supply chain architecture. In the present era, it has become immensely important for retailers, distributors to work closely with their manufacturers to create smart and efficient packaging which will fit retail store shelves and display the right information.

To understand the trends, expectations, challenges, and problems faced by the **customers**, an online survey was conducted among customers from different backgrounds, countries (Figure 5). 132 responses were received out of which 100 were valid and investigated for further analysis.

The problems reported by consumers are as follows:

- **Misleading Labels**: Consumers are more aware and health conscious than ever. They want food packages with accurate information about calories, vitamins, minerals. Similarly, organic, natural, gluten-free, sugar-free and less processed foods are also in trend. However, marketers, sometimes use misleading labels as they provide inaccurate or exaggerated information. Use of scientific term for some of the ingredients also frustrates customers. Most of the Labels which show nutrition information like low fat, skimmed, fat-free, gluten-free, cholesterol free and pure, real fruit juice without artificial flavors are some of the common examples.
- **Lack of Eco-Friendly Packaging:** Several brands these days try to sell their products as environmentally friendly products by calling and labeling "green". However, these products, most of the times, do not meet the required standards. One of the examples is degradable trash bags which do not get decomposed for decades in landfills as compared to biodegradable packaging which gets decomposed in few days. Similarly, most of the Customers are against the use of polythene bags or plastic containers for packaging. or reusable products. Even if there are, there are no clear instructions on the packaging to recycle or reuse them.
- **Size of Packing:** Although a few companies have moved towards small sized packaging or trial packages for portion control for health-conscious customers, most of the manufacturers still do

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not acknowledge this need of customers. Therefore, customers end up buying bigger packing due to the lack of trial packaging.

- **Ease of Use:** Another problem faced by the customers is lack of ease of use. Some of the products have very complex packaging which only adds to the inconvenience and frustration of the customers. For example, canned food products, milk cartons which cannot be opened with bare hands easily.
- **Printing**: Sometimes, Nutritional values, Ingredient used, directions of use on the packaging are written in the small fonts which cannot be read with the bare eyes. Also, there are no specifications given about the ink used on packaging.

It can be seen from above that most of the manufacturers, retailers or distributors tend to ignore the packaging and safety of the product and only focus on the product. Therefore, there is an imminent need to improve the quality management in the food packaging sector with the globalization of food distribution sector and increasing complexity of the food supply chain.

Solution Approach

To identify the solutions to improve the packaging quality, a two-step approach based on new seven (N7) and basic seven (B7) tools (Foster, 2010) was proposed. In step 1, the author investigated the causes associated with various problems and sub-problems associated with poor packaging quality using cause and effect and inter-relationship diagram techniques. In step 2, affinity diagram technique was proposed to develop the solutions.

Investigating Causes of the Problem

For investigating causes related to poor packaging quality problem, Cause and Effect diagram and Interrelationship diagram techniques were used. **Cause and effect diagram**, also known as the Fishbone Diagram or Ishikawa diagram helps in identifying the possible causes of any problem. It helps in discovering the root causes of the various problems. It also enables to uncover bottlenecks in the process and identifies where and why a process is not working. The possible reason for the major problems faced by the packaging industry has been found out here.

Interrelationship Diagram is also called the network diagram. The given diagram showcases the cause–and–effect relationships to analyze the relations and links between the various aspects of the given problems. Here, the author has tried to build an inter-relation diagram between various problems such as lack of sustainability, cost issues, right-sized packaging, printing issues, contamination, Quality, and damages during the transportation and the possible links between them are demonstrated.

Figure 6-7 presents the causes associated with manufacturer related packaging problems namely contamination of food products, cost issues, quality/performance problems, lack of innovation, sustainability challenges, damages during the transportation, finding the right material, and inadequate technology/processing equipment.

Figure 8 presents the results of inter-relationship diagram for the manufacturers. Finding the right packaging material is the biggest issue followed by lack of sustainable practices and contamination.

Figure 9 presents the causes of the packaging quality problems at retailers end namely right sized packaging, unreliable/poor packaging, sustainability challenges, and contamination during transportation.

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Figure 6. Cause and effect diagram for manufactures (I)

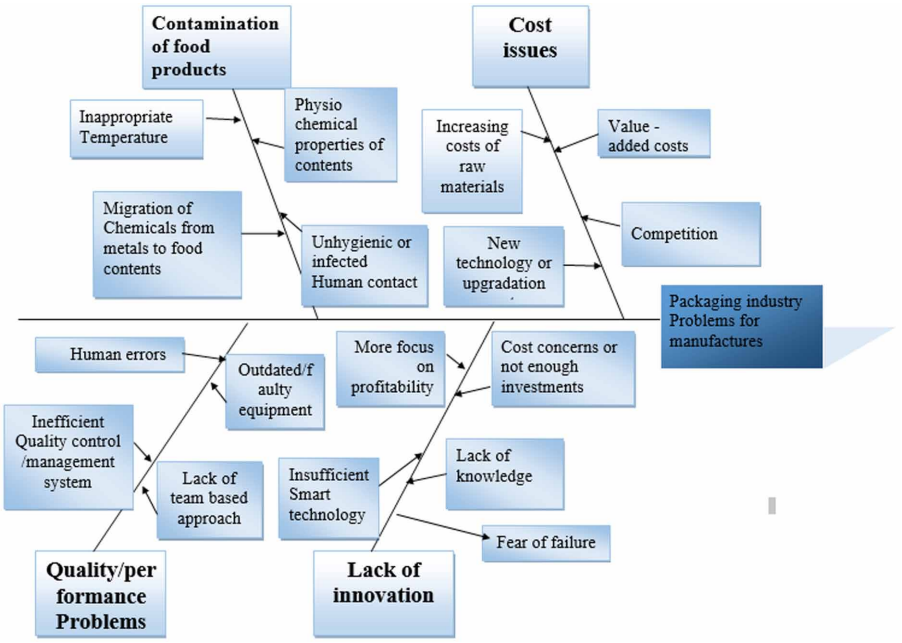

Figure 7. Cause-effect diagram for manufactures (II)

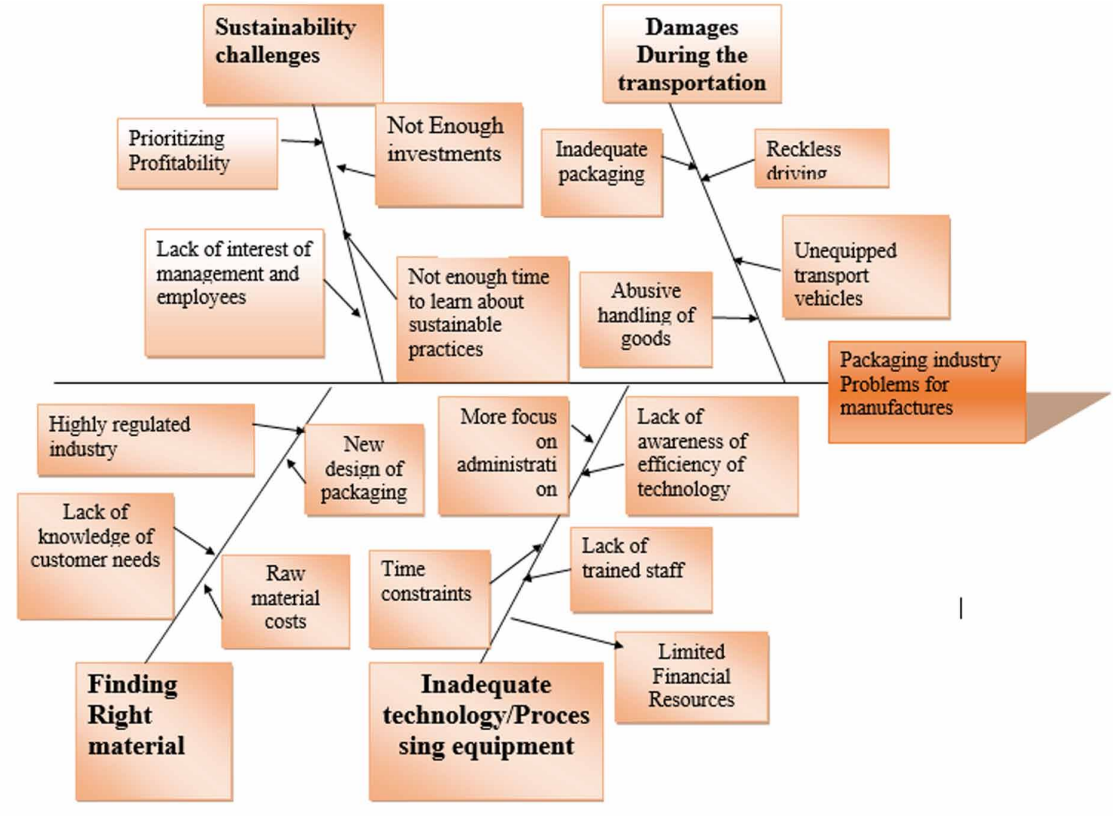

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Figure 8. Inter-relationship diagram of manufacturer problems

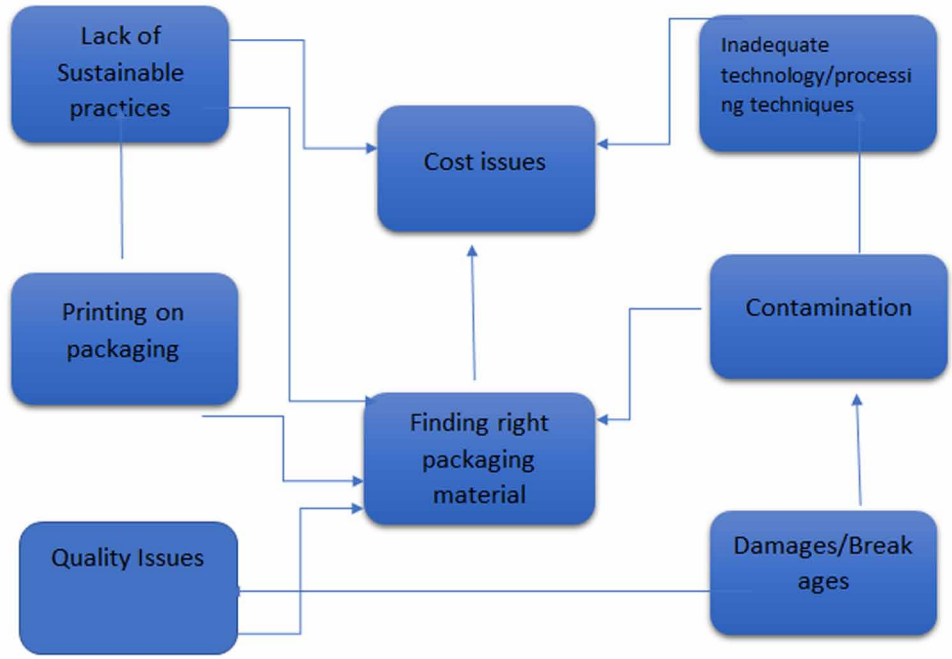

Figure 9. Cause-effect diagram of retailer problems

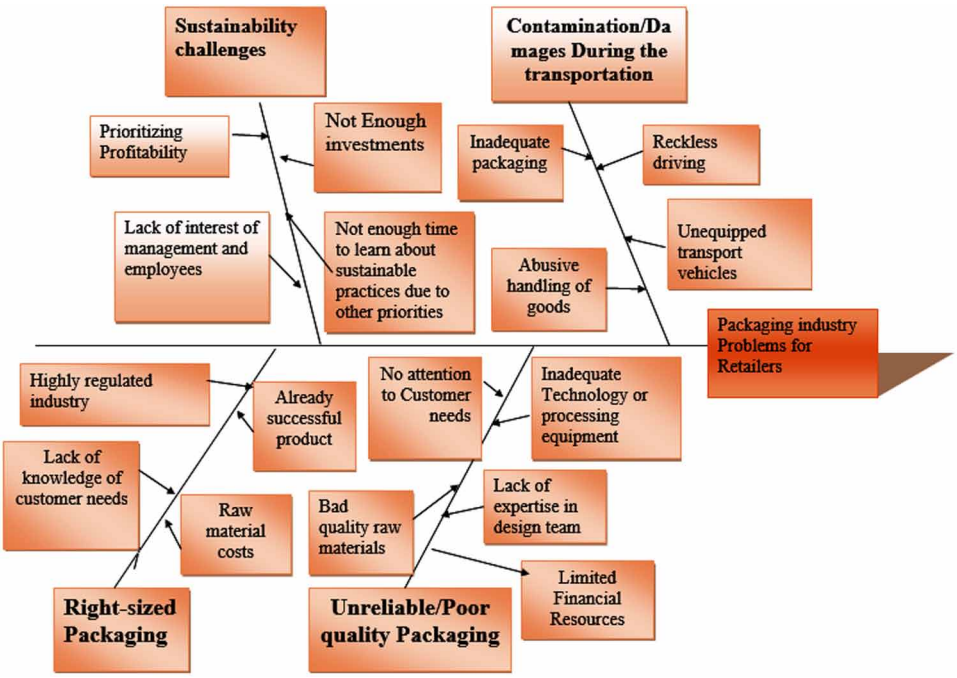

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Figure 10. Inter-relationship diagram of retailer/distributor problems

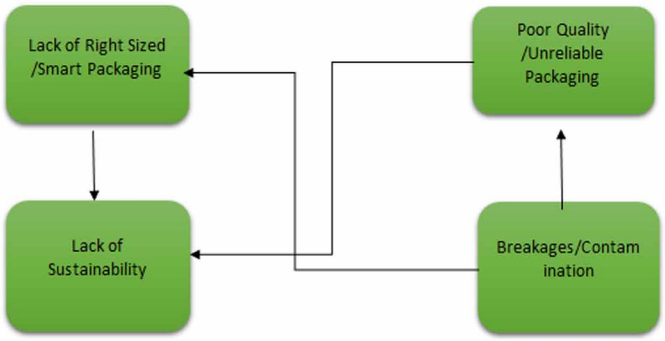

Figure 11. Cause-effect diagram of consumer problems

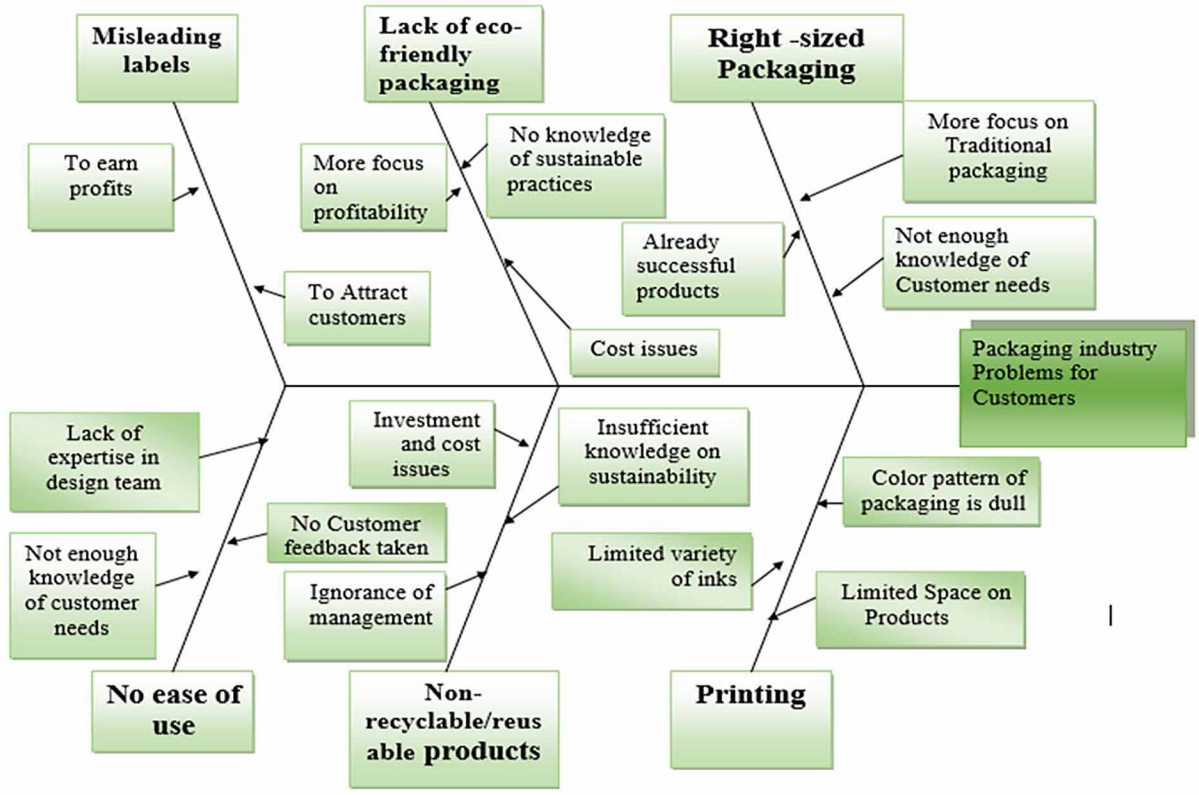

Figure 10 presents the relationship between the various causes of the packaging quality problems at retailer's end. All the four problems namely right-sized packaging, unreliable/poor packaging, sustainability challenges, and contamination during transportation are equally important with the same number of connections (=2).

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Figure 12. Inter-relationship diagram of consumer problems

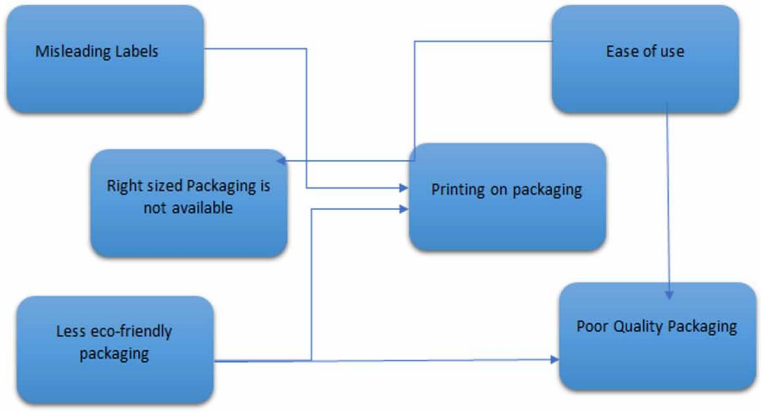

Figure 11 presents the causes for the packaging quality problems at consumers end namely misleading labels, lack of eco-friendly packaging, right-sized packaging, no ease of use, non-recyclable/re-usable products, and printing.

Figure 13. Affinity diagram for solving packaging problems of manufacturers

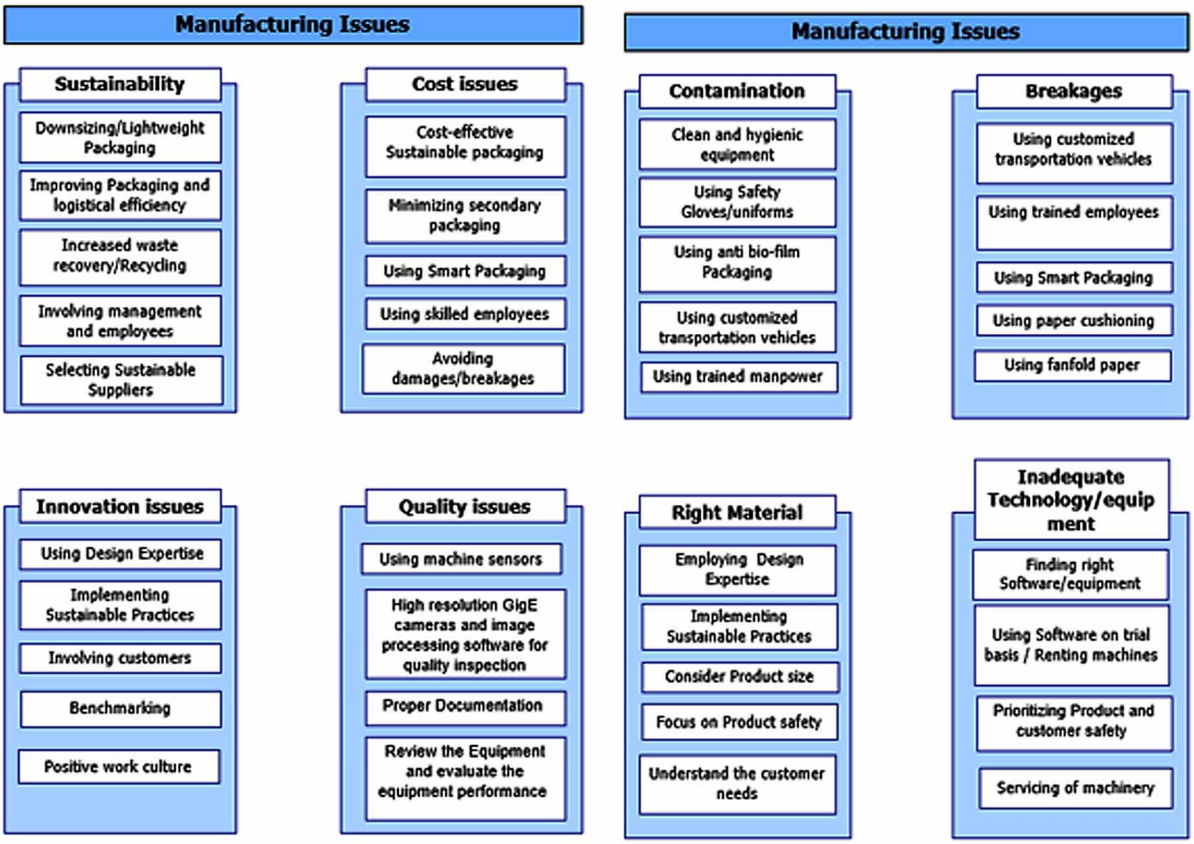

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Figure 14. Affinity diagram for solving packaging problems of retailers /distributors

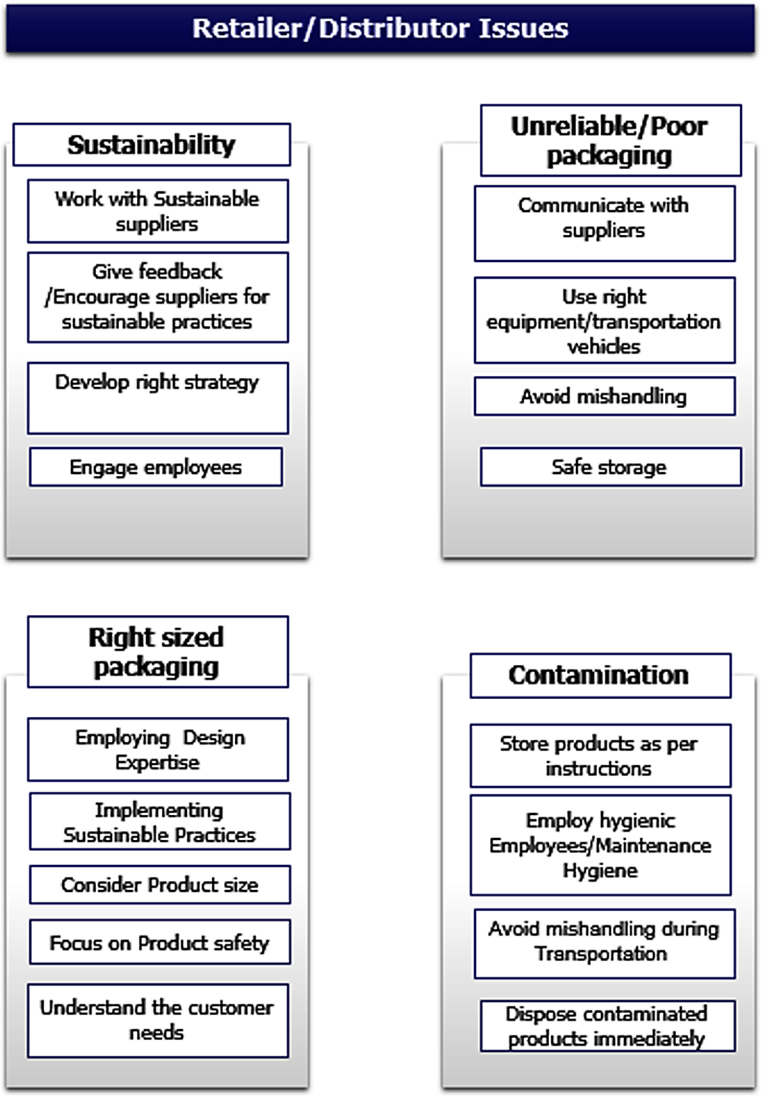

Figure 12 presents the inter-relationship diagram for the consumer problems. Misleading labels and right-sized packaging have least connections and hence less important than the other four.

GENERATING SOLUTIONS AND WHAT-IF PLANS

The solutions to improve packaging quality were generated using Affinity diagram technique. An **affinity diagram** includes gathering of the problem, sub-issues and associated solutions or ideas that need to be addressed.

Figures 13-14 present the affinity diagram results for the major challenges faced by the manufacturer, retailer and the consumers of the Packaging industry. The major issues addressed are sustainability,

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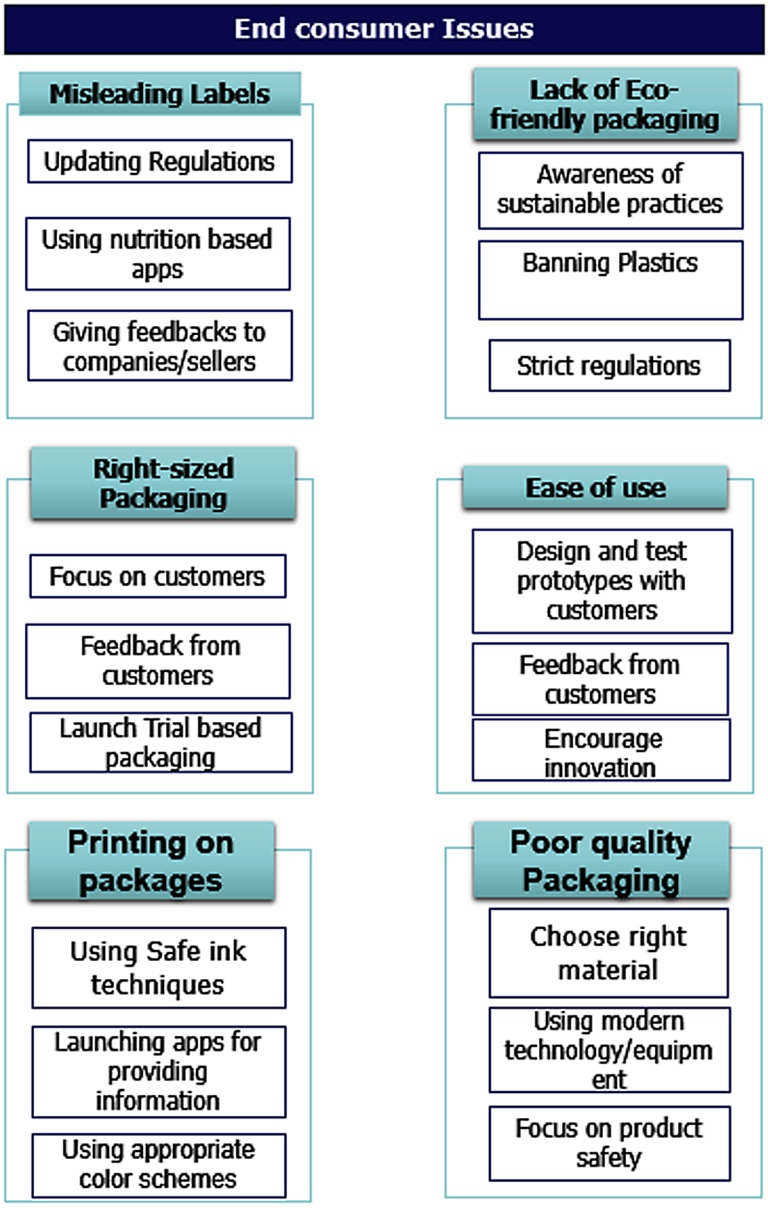
Figure 15. Affinity diagram for solving packaging problems for customers



cost-related issues, lack of innovation, Quality issues, contamination, inadequate technology, damages and finding the right material.

The expected results after application of the proposed solution techniques for improving quality in food packaging sector are more sustainable packaging and use of sustainable materials, more traceability in supply chain with increased effective communication using software and web-based solutions, introduction of more innovative and smart packaging techniques, less wastage during packaging process, customer friendly designs with ease to open and utilize, better insight into customer needs, right information on labels using sustainable printing technologies, active participation of employees in manufacturing, retailing and distributing units and cost-effective supply chain

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CONCLUSION AND FUTURE WORKS

In this paper, the author investigated the subject of packaging quality in food supply chains and proposed a solution approach based on new (N7) and basic tools of quality (B7). To improve and manage the quality of food packaging, it is important to understand the supply chain of the food packaging sector and analyze the difficulties and challenges faced by these actors. Sustainability, employees' participation, traceability and Collaboration of various supply chain actors using effective means of communication can be proven as key factors to improve the quality in food packaging sector. Hence, it can be stated that the right implementation of tools and techniques suggested will help in overcoming the difficulties faced in the food packaging supply chain.

The current approach is based on limited respondents, future studies can work on additional data to generalize the results. The study could also be extended across various industry types to study the impact of context, location, culture, and sector on quality issues. Lastly, many other quality techniques can be used for quality improvement and results compared with the proposed work.

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Chapter 13
Using Six Sigma to Achieve Sustainable Manufacturing

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ABSTRACT

Sustainability has been widely discussed from different points of view. Manufacturing is contributing a critical part of noncompliance to environment and human rights in the modern society. While a lot of companies are seeking strategies to either promote corporation image or stimulate employees' work passion, most of research and guidelines are focusing on how to measure the sustainability based on the cases from big firms. Most of manufacturing firms are medium and small sized; they are searching for a comprehensive and systematical way to implement sustainability practice step by step without using very experienced professionals. This chapter is supplying a systematic framework for firms to achieve sustainability in manufacturing environment with the widely used problem solving tool Six Sigma. Inexperienced professionals will be able to implement the sustainability practice from defining problems to achieving leadership in sustainability. It illustrates how to customize the framework content based on individual needs.

INTRODUCTION

Sustainability has been widely discussed from different points of view. As one of the most important parts of Sustainable Supply Chain, Sustainable Manufacturing is inheriting the genes of Sustainable Supply Chain Management. Among all the activities along supply chain, manufacturing has been considered as one of the biggest contributors for environmental pollutants and work-related injuries. Especially the work environment of the manufacturing plants in the developing countries is receiving lots of criticism. Besides, companies across the world are facing the increased cost in materials, energy, and compliance coupled with higher expectations of customers, investors and local communities (Wyckoff, 2005).

Except the needs to achieve the sustainable manufacturing environment, there are also plenty of benefits that have been observed. For example, a 2010 survey of UK-based manufacturing SMEs shows that 56% are already investing in low-carbon technologies and strategies. The global market for low-

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carbon products is already estimated to be worth over USD 5 trillion and growing. Also, the sustainable manufacturing companies are receiving higher financial benefits and better company reputation than those who are facing profound sustainability problems (Wyckoff, 2005).

In order to help companies to achieve sustainable manufacturing environment, there should be flexible and comprehensive framework to help companies who are new into this area to understand their current situations and find corresponding solutions while still can be controlled and improved in a continuous behavior. Most of the articles or handbooks are giving emphasize on how to measure sustainability, while there are rarely comprehensive work routine for a company to start achieving sustainable manufacturing from zero.

Six Sigma as a problem-solving tool has been widely used for different sectors to achieve higher performance in an organization. It supplies a comprehensive framework to solve any critical problems, especially there are a lot of tools can be used.

The combination of Six Sigma and Sustainable Manufacturing can give any organization a systematic framework with abundant tools to make changes to current manufacturing environment in order to achieve sustainability goals. Due to the flexibility and various tools that can be used, different organization can customize its own specific execution routine based on their own resources and vision. It won't restrict to any industry, and it can be also applied to others when the detailed industry information is supplied.

This chapter is contributing to the hot topic related to sustainable manufacturing while it can still be very practical and easy to implement.

The research and work practice mentioned in these literatures are putting a lot of efforts on the concepts of sustainable manufacturing and the measurement methods that can be used to measure the performance of sustainability.

While for a lot of organizations, it is necessary to understand how to align these separate concepts, tools together to successfully achieve sustainable manufacturing from zero. There needs systematical way to help organizations to execute sustainable manufacturing from understanding to real implementation.

At the same time, a lot of measurement metrics that have been mentioned in different literatures are not feasible for small and medium sized organizations to really collect the data, such as carbon dioxide emission. It will be helpful to get comprehensive summary and validation of these metrics for more suitable usage.

What's more, sustainability includes broad range of topics and requirements, in reality not everything can be achieved at the same time. The sequence and interaction of these three factors should be fully investigated to understand the work priorities under different circumstances.

The research objectives are summarized below:

- How do organizations be aware of sustainability?
- What are the proper metrics for sustainable manufacturing?
- How can organizations analyze sustainability problems?
- How can organizations improve sustainability performance?
- How can organizations achieve leadership?

The contribution and differences of this study compared with previous research are also categorized as below:

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- Develop generic framework that can tackle any sustainability area with systematic approach
- Build framework for small to medium sized company (In Canada, 99% of companies have fewer than 100 employees) (Daly, 2000)
- Categorize measurement target levels
- Identify specific metrics for sustainability measurement
- Quantitative and qualitative analysis for sustainability performance
- Build continuous improvement cycle
- Test this framework in a manufacturing plant to validate the usage of each step

BACKGROUND

Sustainable Manufacturing

Sustainable Supply Chain Management is including different activities with regard to different levels of decisions, while most of the waste and inhuman activities are directly related to manufacturing operational level. Nearly a third of the world's energy consumption and 36% of carbon dioxide (CO2) emissions are attributable to manufacturing activities (2013 Global Greenhouse Warming, 2013). Manufacturing activities are also integrated in suppliers' activities and distributors' activities, which will have significant impact on the environment.

In addition, manufacturing sectors have been the subject of intense public scrutiny and criticism for their human rights performance abroad. Also, these industrial sectors illustrate challenges of corporate human rights responsibility and implications for corporate policies that are common and applicable to most other sectors (Kaeb, 2008). Sustainable manufacturing helps companies to save money, enhance competitiveness, and reduce environmental, health, and safety impacts. According to a recent survey, two-thirds of nearly 3,000 company officials surveyed responded that "sustainability was critically important to being competitive in today's marketplace." (Haanaes, et al., 2012) In addition, as an indication of company sustainability initiatives and stakeholder interest, 93 of the S&P 100 companies reported sustainability information on their websites in 2008 (Mohan, 2010).

As part of Sustainable Supply Chain Management, Sustainable Manufacturing is also inheriting the benefits from Sustainable Supply Chain Management, the key benefits for Sustainable Manufacturing are:

- Lower Resource and Production Costs
- Lower Regulatory Compliance Costs
- Improved Sales and Brand Recognition
- Greater Access to Financing and Capital
- Easier Employee Hiring and Retention

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Tools for Sustainable Manufacturing

Green Manufacturing

Green manufacturing deals with maintaining sustainability's environmental, economic and social objectives in the manufacturing domain. Reducing hazardous emissions, eliminating wasteful resources consumption and recycling are examples of sustainable green manufacturing activities (Deif, 2011).

The importance of Green manufacturing has been discussed by a few articles. Peter Yacob (Yacob, Wong, & Khor, 2019) has discussed framework that can be used as green initiatives for Malaysian manufacturing SMEs. (Naderi (Naderi, 1996)showed that green manufacturing is highly tied to waste management through the elimination of causal factors. Jovane et al. (Jovane, Koren, & Boer, 2003)presented sustainable and green manufacturing as future paradigm with business model based on designing for environment using new nano/bio/material technologies. They highlighted that the new paradigm will respond to the customer need of more eco-friendly products. Wang and Lin (Wang & Lin, 2007) proposed a broad triple bottom line framework to track and categorize sustainability information at the corporate level through a sustainability index system. The framework incorporated environmental and social costs and values into economic activities to support the decisions of the management. Their methodology was suggested to help decision makers to make green manufacturing plans. Burk and Goughran (Burk & Goughran, 2007) also presented another framework for sustainability to realize green manufacturing. The framework was based on their studies of SME manufacturers who achieved ISO 14001 certification (Deif, 2011).

Various analysis tools and models have also been proposed before. Melnyk et al. (Melnyk, Sroufe, Montabon, & Hinds, 2001) proposed Green MRP tool. This tool is essentially a conventional Material Requirements Planning system that has been modified to include environmental considerations when converting the Master Production Schedule into the various component schedules. Through this inclusion, Green MRP solves the problem of minimizing environmental impact when managing industrial waste, by flagging potential component planning and environmentally related problems. Hui et al. (Hui, He, & Dang, 2002) proposed a model to assess environmental hazards in manufacturing. In their model, the network analytic method was employed to analyze the potential of each impact category created by different kinds of waste in manufacturing processes. For realizing green manufacturing on the machine level, Krishnan et al. (Krishnan, Raoux, & Dornfeld, 2004) proposed environmental value systems analysis tool to evaluate the environmental performance of semiconductor processing. The tool develops environmental assessments through a "bottom-up" analysis approach, assembling equipment environmental models to describe a system. Cleanability and burr reduction which are another green manufacturing aspects also on the machine level were studied in various machine tool researches to act as another optimization objectives in their attempts to improve machine tool performance. Example of this type of work was presented by Avila et al. (Avila, et al., 2005) in the aerospace industry.

Lean Manufacturing

Lean Manufacturing is playing an important role in reducing the waste. While Lean Manufacturing is not only considering from the point of the environmental impact, it is mainly based on the point of maximizing the value for end users, which not necessarily includes the reduction of natural resources, but also includes the reduction of human resources.

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Lean production is a multi-dimensional approach that encompasses a wide variety of management practices, including just-in-time, quality systems, cellular manufacturing, supplier management, etc. The core thrust of lean production is that these practices can work synergistically to create a streamlined, high quality system that produces finished products at the pace of customer demand with little or no waste (Shah & Ward, 2003).

The lean thinking can be summarized in five principles "precisely specify value by specific product, identify the value stream for each product, make value flow without interruptions, let the customer pull value from the producer, and pursue perfection". By clearly understanding these principles, and then tying them all together, managers can make full use of lean techniques and maintain a steady course" (Ravet, 2011) (Womack & Jones, Lean Thinking: Banish Waste and Create Wealth in Your Corporation, Revised and Updated, 2003).

Lean and green strategies are often seen as compatible initiatives because of their joint focus on waste reduction (Mollenkopf, Stolze, Tate, & Ueltschy, 2010). Research has been done on using Lean and Energy Saving and Emission Reduction strategy (Cai, et al., 2019) as well. The divergence and convergence for these two approaches are examined in details (Ramos, Ferreira, Kumar, Garza-Reyes, & Cherrafi, 2018). According to Ravet (Ravet, 2011) lean production and sustainable supply chain create their "eco- advantage" in three main ways:

- Eco-efficiency (cutting out waste, using resources productively, and minimizing the carbon footprint) Lean methods can develop sustainable green practices, particularly in the area of waste reduction.
- Eco-innovation (improving product and service designs so they're based on green processes by products and designing for recycling)
- Eco-transparency: gaining and sharing full visibility into the value chain so that your business can promote its green brand and enhance and protect its overall brand.

SIX SIGMA IN SUSTAINABILITY

Six Sigma in Manufacturing

Since the introduction of Six Sigma in Motorola, Six Sigma has been implemented in a wide range of industries. The successful financial returns have encouraged different organizations to take Six Sigma initiative. The Table 1 summarizes the reported benefits from manufacturing sectors.

Six Sigma in Sustainability

Many projects that are related to sustainability development have been conducted using Six Sigma approach. As a leading global supplier of high performance specialty chemicals and coatings, Enthone has demonstrated good examples of the applications of Six Sigma in Sustainability development. The project of Reduction of Plastic Packaging has resulted in a 20% reduction in plastic packaging while providing environmental benefits. Additionally, the project of Reduction in Energy Usage resulted in a significant annual cost savings, primarily by consolidating into larger batches being manufactured. This has resulted in less waste treatment and has resulted in a 10% reduction in energy usage (Enthone,

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Table 1. Reported benefits from Six Sigma in manufacturing

Company/project	Metric/measures	Benefit/savings
Motorola (1992)	In-process defect levels	150 times reduction
Raytheon/aircraft integration systems	Depot maintenance inspection time	Reduced 88% as measured in days
GE/Railcar leasing business	Turnaround time at repair shops	62% reduction
Allied signal (Honeywell)/Iaminates plant in South Carolina	Capacity Cycle time Inventory On-time delivery	Increased to near 100%
Allied signal (Honeywell) /bendix IQ brake pads	Concept-to-shipment cycle time	Reduced from 18 months to 8 months
Hughes aircraft's missiles systems group/wave soldering operations	Quality/productivity	Improved 1,000%/Improved 500%
General electric	Financial	$2 billion in 1999
Motorola (1999)	Financial	$15 billion over 11 years
Dow chemical/rail delivery project	Financial	Savings of $2.45 million in capital expenditures
DuPont/Yerkes plant in New York (2000)	Financial	Savings of more than $25 million
Telefonica de espana (2001)	Financial	Savings and increases in revenue 30 million euro in the first 10 months
Texas instruments	Financial	$600 million
Johnson and Johnson	Financial	$500 million
Honeywell	Financial	$1.2 billion

Source: (Weiner, 2004) (de Feo & Bar-El, 2002) (Antony & Banuelas, 2002) (Buss & Ivey, 2001) (McClusky, 2000)

2013). What's more, 3M as a pioneer in corporate pollution prevention, it has implemented sustainability development with the help of Lean Six Sigma. Over the last 31 years, the program has prevented more than 2.6 billion pounds of pollutants and saved more than $1 billion based on aggregated data from the first year of each 3P project (EPA United States Environmental Protection Agency, n.d.).

Another technique that is widely discussed is Lean Six Sigma. It evolves from Six Sigma with DMAIC framework but also involves green concepts (Park & Linich, 2008). It is interesting to be noted by Alessandro: leadership is a requirement for successful Lean Six Sigma deployment in organizations, and critical to sustaining improvement and Lean Six Sigma is an effective leadership development tool (Laureani & Antony, 2019). While it has been implemented in different organizations, the focus of Lean Six Sigma is mostly to reduce waste and environmental impact. It lacks of emphasis on social impact which is becoming more and more crucial in developing countries, especially in Asia and Latin America which is the hubs for production activities.

SOLUTION APPROACH

The solution provided is evolved from Six Sigma and Achieving Excellence System with the concepts of sustainability. Previous research is focused on how to tackle specific area of sustainability, such as reducing emission, meeting human rights standard. There was no framework to address sustainability areas in a systematic way. This solution can be used to address sustainability issues as a business im-

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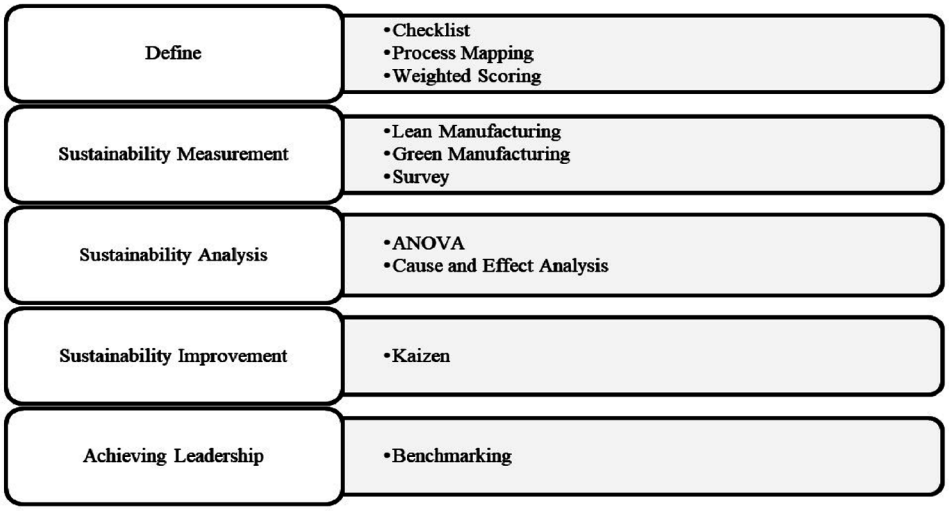
Figure 1. Solution phases and main tools



provement case with systematic way. It can be used more than just manufacturing process, but generically in all major sectors. However, this research has been tested with manufacturing process as validation.

There are five phases to achieve sustainable manufacturing, Define, Sustainability Measurement, Sustainability Analysis, Sustainability Improement and Achieving Leadership. This solution is applied as case study in an aerospace manufacturing plant in Montreal Canada to simulate the approach. All steps are shown with simulated data to present its specific application. Figure 1 has shown the five phases with the main tools used in each phase.

Figure 2. Link between problems and solutions

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The link between the remaining research problems and proposed solution framework is showing in Figure 2.

STEP ONE: DEFINE

Preliminary Check

The first question that should be asked is whether the organization has been aware of the sustainability impact. A preliminary checklist shown in Table 2 can be used as a survey to understand the level of implementation of such practices among employees. The checklist will provide an overview of the understanding of sustainability development in a manufacturing environment. The items will be separated for three groups. The first group is for employees who are working under office environment, such as supply chain planner, accountant, etc. This group of employees is aware of the general policies of companies, while they are not the ones that are experiencing the sustainability initiatives directly and intimately. The second group is for employees who are doing the manual labor work under manufacturing environment, such as assembly workers, transportation drivers, testers, etc. This group of people is directly facing the challenges of sustainability development and witnessing the outcomes of manufacturing activities, such as polluted water, work-related injuries, etc. The third group is targeting the management, who is directing the development of sustainability. This group is reflecting the commitment and awareness of sustainability development for the company.

Table 2. Preliminary checklist for understanding of sustainability

Item	Checklist
For office employees	
1. Do you know sustainability?	Y/N
2. Do you think that XX Company is implementing sustainability initiative?	Y/N
3. Do you expect the implementation of sustainability if it is not implemented?	Y/N
For manual labor workers	
1. Do you have or witness any pollution activities during production?	Y/N
2. Do you have any injuries related to work?	Y/N
3. Are there any practices that are used to recycle the wastes and pollutants?	Y/N
4. Do you feel that the XX Company is making changes to use less polluted components, such as plastics, lead, etc.?	Y/N
For management:	
1. Do you know sustainability development?	Y/N
2. Are you interested in sustainability development?	Y/N/Maybe
3. Is there any policy that is related to sustainability development in XX Company?	Y/N/Not Sure
4. Is XX Company is willing to invest in sustainability development?	Y/N/Maybe
5. Do you know the benefits of sustainability development?	Y/N

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From the checklist survey, it gives analysts general view of the understanding of sustainability development. Based on this, analysts are able to develop more specific investigation with regard to the obstacles and futures for sustainability development under the manufacturing environment.

Management Commitment Investigation

As a key factor for implementing sustainability development and Six Sigma, it is crucial to understand the level of commitment from management and its restrains. The following aspects should be investigated:

- The strategic goals of the current management?
- What are the current manufacturing benefits?
- How much of investment XX Company is willing to allocate?
- What are the obstacles for implementing sustainable strategy under the manufacturing environment?
- What are the expectations that the management are expecting from the implementation of sustainability development in the manufacturing environment?

It is encouraged that the investigation is under a confidential environment, and it could include the management from different functions. It is good practice to draw or figure out the organization chart before the investigation, since the right target of interviewees will have better influence for the understanding of current management commitment and its implementation for the future projects.

Current Process Mapping

After the investigation of management attitude for the implementation of sustainability development under manufacturing environment, it is essential to clearly understand the work flow of the manufacturing environment.

The tool can be used is called Process Mapping, which is a workflow diagram to bring forth a clearer understanding of a process or series of parallel processes. The following steps can be used to complete a clear process diagram (Ahoy, 1999):

- Determine the boundaries, meaning the begin and end;
- Use verbs to list all the steps;
- Sequence the steps;
- Check the resources and constrains;
- Draw appropriate symbols;
- Link the resources and constrains with the steps.

In order to assess the sustainability development, the 5M elements that are widely for lean production can be used to understand clearly the input and output of the process (Wee & Wu, 2009):

- What the *materials* are involved as input and output?
- What are the *methods* that have been used to produce the products?
- What are the *machines* used during the production process?
- What kind of *man power* is used during the production process?

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Table 3. Preliminary project selection scorecard illustration

Process	**1**	**2**	**3**
Material Utilization Rate	1	3	3
Labor Working Environment	3	5	1
Pollution Impact	5	1	5
Importance for the manufacturing	1	5	1
Investment	3	1	1
Final Score	13	15	11

- How much *money* has been invested in different steps?

By asking these 5M questions, it will help the analyst to clearly understand how each step of production activity has been practiced in reality. Besides, it will supply basic ideas for the future measurement and analysis with regards to sustainability development under the manufacturing environment.

Preliminary Project Selection

After understanding the company business vision from management and current manufacturing process, the analyst need to identify the specific sustainability development projects due to the limited resources and wide range of sustainability development feasibility. It is not easy and feasible to implement all the sustainable practices at the same time for all the manufacturing process. There should be some selection criteria to help analyst and management team to identify the project that will mostly address the critical problems relating to sustainable development at the current stage.

From Table 3, an illustration sample, it can be concluded that process 2 has highest score for sustainability improvement. The detailed criteria assessment methods are in details below.

For each process or step that is recognized in the process mapping, it is helpful to do a preliminary assessment of the sustainability development and to determine which process or step should be improved first based on the different criteria:

- Material Utilization Rate: To assess whether the raw materials have been appropriately transformed into final products. It describes the difference between the raw material weight used to produce a part and the actual weight of the finished part. The higher the percentage of utilization, the better and more economical the stamping process (FMA Communications Inc., 2001). The following equation can be used as a preliminary assessment for the manufacturing department to understand whether the raw material is under proper usage and if there is huge amount of waste. The criteria will be given by 1, 3 and 5 scheme, where 1 means the material utilization rate is high (MUA is between 75%~100%), and 5 means the utilization rate is very low (MUS is between 0~40%).

Equation 1:

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Table 4. Labor working environment evaluation illustration

Elements	Weight	Evaluation	Weighted Evaluation
Clear working guidance	25%	1 (meaning good guidance)	0.25
Natural working environment	25%	5 (meaning the labor is exposed to very unhealthy working situation)	1.25
Excessive working time	25%	1 (excessive working time is rare)	0.25
Work related injuries	25%	5 (there are a lot of injuries related to work)	1.25
Total Weighted Evaluation			**3**

$$\mathbf{MUA} = \frac{\mathbf{Actual\ Weight\ of\ the\ Material\ in\ the\ Final\ Product}}{\mathbf{Total\ Raw\ Material}} \times 100\% \quad (1)$$

- Labor Working Environment: The most important elements that should be considered for process improvement are: clear working guidance, natural working environment (i.e. if the labor is exposed to the poisonous chemicals, the water and air consumed is clean and safe, etc.), excessive working time and work related injuries. The scheme for each element is 1, 3 and 5. An evaluation example is showed in Table 4 for illustration.
- Pollution Impact: This can be evaluated based on the input and output from the process mapping. Due to various definitions of the pollutants from different organizations, in this article, we put pollutants into three big categories. If the pollutants and/or waste are existing in all three categories, it should be given 5 points as an indicator if improvement, otherwise it can be given 1 point.
  - Liquid Pollutants (Pollutants, 2005):
    - acids - hydrochloric, acetic, fumaric, sulphuric, nitric, benzoic
    - bases - hydroxides of sodium, calcium, magnesium
    - carboxylic compounds
    - nitrogenous wastes
  - Air Pollutants: Ozone, Particulate Matter, Carbon Monoxide, Nitrogen Oxides, Sulfur Dioxide and Lead (US Environmental Protection Agency);
  - Solid Waste: Biodegradable waste, Recyclable material, Inert waste, Electrical and electronic waste, Composite waste, Hazardous waste, Toxic waste and Medical waste (Wikipedia)
- Importance for Manufacturing: This is a criteria to help organization to prioritize if the sustainable development should be implemented in this process based on its importance for the whole manufacturing process. From low to high importance, 1, 3 and 5 points will be allocated accordingly.
- Investment: As for the improvement of a sustainable manufacturing process, it is also crucial for a company to understand how much investment it can be affordable due to the complexity of the problems that have been demonstrated before. For example, after the evaluation of previous work, the management and analysts will decide if there will be a huge amount of investment for the particular process and if the investment can be affordable for the company. A simple equation will help the organization to give indicator for this criteria. If the calculation is between 0~50%, 5 should be given as it is not big financial burden for the company to improve and continuous im-

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provement is possible for Six Sigma projects, if the calculation is between 51%~100%, 3 should be given, otherwise 1 should be given to indicate that the investment is big financial burden that the company might not be able to continuously improve.

Equation 2:

$$\mathbf{Invetment\,Feasibility} = \frac{\mathbf{Investment\,needed}}{\mathbf{Invetment\,affordable}} \times 100\% \tag{2}$$

Other elements should be addressed at the same time when the Six Sigma projects are to be selected, for instance, if the organization is considering that investment has high impact for the successful implementation for the sustainable development, then it should be given high weight when we make the decision. Under this circumstance, the weighted scorecard can be used as a final decision making tool as demonstrated in Table 5.

The weighted score give us a more comprehensive understanding from current objective situation and subjective opinions from the organization. It shows that Process 2 should be the first project for sustainability development due to the financial accessibility for the continuous improvement.

Table 5. Weighted scorecards for project selection

Item		Process 1	Process 2	Process 3
MUA	Original Score	1	3	3
	Weight	20%	20%	20%
	Weighted Score	*0.2*	*0.6*	*0.6*
Labor Working Environment	Original Score	3	1	5
	Weight	15%	15%	15%
	Weighted Score	*0.45*	*0.15*	*0.75*
Pollution Impact	Original Score	1	3	5
	Weight	10%	10%	10%
	Weighted Score	*0.1*	*0.3*	*0.5*
Importance for the Manufacturing	Original Score	3	3	5
	Weight	5%	5%	5%
	Weighted Score	*0.15*	*0.15*	*0.25*
Investment	Original Score	1	5	3
	Weight	50%	50%	50%
	Weighted Score	*0.5*	*2.5*	*1.5*
Final Weighted Score		**0.95**	**3.7**	**3.6**

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STEP TWO: SUSTAINABILITY MEASUREMENT

During this phase, organization will need to identify different criteria to measure the sustainability development status in manufacturing environment. Different methods can be used during the measurement phase, for example, internal audit, employee questionnaire, etc. Based on the scale of a company or the products the company is producing, numerous metrics or questions can be formulated for the investigation. While for the modelling purpose of this paper, there is a framework for the measurement, which involves three general steps to conduct the measurement systematically.

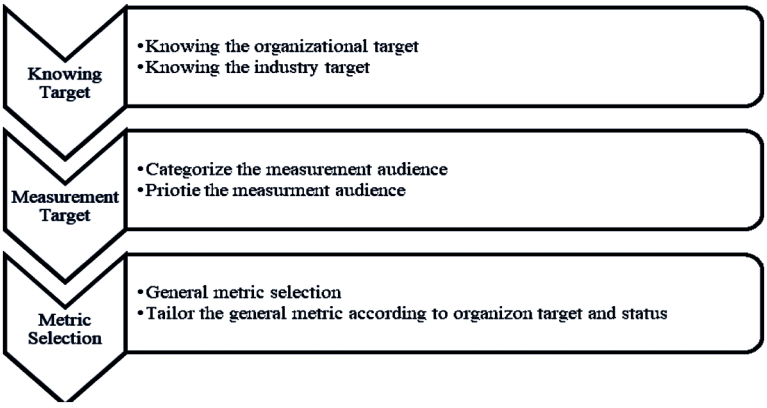
Except the general steps listed, one of the most critical areas in measurement phase is to define the measurement metrics. Reviewing from different articles and industry reports, three categories of sustainability measurement for manufacturing are proposed, Lean measurement, Green Measurement and Social Assessment. They will form a comprehensive roadmap to gather information regarding how the sustainability practices have been implemented in manufacturing environment and they will give clear and detailed picture of the situation and problems the company is facing now. But these categories are not exclusively independent; there will be intersection points among each category, such as measurement of poisonous chemicals will also have impact on green and social assessment. There is no specific step for which category of investigation goes first, but it will be more objective to use external auditing team or temporary team to implement the investigation to keep information accurate.

General Measurement Step

In order to assess the sustainability development status, there are general steps shown in Figure 3 to follow in order to understand the targets and the extent to which the organization is performing.

The first step is to understand the target of the organization and the industry. It is essential to understand what the organization's expectations and what the industry's requirements and trend in order to be competitive. Different organization and industry have their own characteristics and obstacles in order to achieve the sustainability mission, for example, the ISO 14001:2004 (ISO, n.d.) has set general targets to achieve environmental friendly management system, and for Canada government, there is Federal

Figure 3. General manufacturing sustainability measurement steps



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Sustainable Development Act (Environment Canada, n.d.) effective since 2008. There are always different targets, regulations to achieve; it will influence how the organization measures the sustainability.

Second step is to categorize the measurement target, whom the organization will conduct the measurement. For example, if the company is mainly a software R&D center, which mainly performs the design and research activity, then the manufacturing sustainability audience might be the contractors who actually do the production of chips. Besides, since different levels will reflect different concerns for the company, at what level of the measurement should be done is also an aspect to consider. For instance, do we need to involve the senior management or on-site manual labor workers, do we need to involve all the contractors and so on. If we involve different levels of measurement, the way and content to conduct the measurement will differ from one to another. Additionally, there are different opinions from various backgrounds, as a company, there is need to set priorities for which voice should be emphasized in order to make better use of current resources and align with company's future vision.

After understanding the expectations and measurement target, it is necessary to select the metrics or ways to measure the sustainability status. It can be quantitative and/or qualitative based on the needs and feasibility. After careful selection, organizations need to tailor the metrics based on their own needs and feasibility.

Lean Measurement

Under the manufacturing environment, lean practice can help to measure if there is any waste which is also a big part as sustainability development. It will help organizations to identify which process has been tremendous contribution for the materials waste. But lean is not necessarily can be fully implemented into sustainability development. Lean is focusing on all waste that will not add direct value to the customer's payment. For example, if there the organization identify that one employee should manufacture more products at certain period to add more value to the machine, it might be burden to employee's health if the work load is strengthened. So, when the lean thinking is applied for measurement of sustainability development, it should be balanced with social impact thoughts.

The typical seven types of waste that should be measured are:

- Transport (moving products that are not actually required to perform the processing)
- Inventory (all components, work in process and finished product not being processed)
- Motion (people or equipment moving or walking more than is required to perform the processing)
- Waiting (waiting for the next production step, interruptions of production during shift change)
- Overproduction (production ahead of demand)
- Over Processing (resulting from poor tool or product design creating activity)
- Defects (the effort involved in inspecting for and fixing defects) (Womack & Jones, Lean Thinking: Banish Waste and Creat Wealth in Your Corporation, 2003) (Wikipedia, 2013)

Based on the seven types of waste, the sustainability waste measurement can be developed:

- Internal movement distance: This includes the distance that has been covered by the forklift, conveyer belt etc. It usually shows how much oil, gas and electricity has been consumed by the unnecessary movement of the different transportation equipment inside of the plant. Additionally,

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Table 6. Lean sustainability measurement

Measurement	Indicator	Hint
Internal Movement Distance	Meter	Energy resources consumed
		Air pollutants released
Excessive Inventory	per material volume	Excessive energy consumed
		Pollutants and chemicals driven by suppliers
Non-production time	Minute	Excessive energy consumed
		Source for unpleasant noise for employees
		Source for chemicals released
Unnecessary production time	Minute	Excessive energy consumed
		Excessive raw materials consumed
		Illegal working time for employees
Amount of chemicals	Per material volume	Air, solid and liquid pollution

it will indirectly indicate the carbon dioxide impact from the internal movement, which is not easy to measure in most of the cases.

- Excessive inventory: This measures the materials that will not be used for the planned production, especially the products and raw materials that will include the pollutant and poisonous elements mentioned before. Since the need of these materials will drive the production from its suppliers, this will have profound impact through the flow of the supply chain.
- Non-production time for the machine: This inspects the time when the machine is waiting for the next production while still on power. It will demonstrate the waste for electricity, gas and other power resources. Additionally, if the machine is a source of noise and might release non-environmentally friendly chemical or air elements, it will indicate the impact for the environment and employees' working situation.
- Unnecessary production time: This indicates the time that is used to produce the products that are not ordered directly from customer while just for the safe inventory purpose. The excessive production will lead to illegal or unpleasant working environment for employees. In addition, it will drive the unnecessary procurement and supply from its suppliers.
- Amount of chemicals: This measures how much of chemicals we procure and use for the processing of the final products. The amount of chemicals will show the impact it can bring to its processing employees who are exposed to these unhealthy elements. Besides, it will show how much pollution it can bring to the environment when it is disposed.

These measurements are summarized in Table 6 with its indicators:

Green Measurement

As there are a lot of different indicators developed by different organizations and individuals, the main questions that should be asked for the environment impact are below in brief:

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Table 7. OECD green manufacturing indicators (*OECD, n.d.*)

Inputs	Operations	Products
Non-renewable materials intensity	Water intensity	Recycled/reused content
Restricted substances intensity	Energy intensity	Recyclability
Recycled/Reused content	Renewable proportion of energy	Renewable materials content
	Greenhouse gas intensity	Non-renewable materials intensity
	Residuals intensity	Restricted substances content
	Air releases intensity	Energy consumption intensity
	Water releases intensity	Greenhouse gas emissions intensity
	Proportion of natural land	

- How much raw materials are used?
- How much renewable resources are used?
- How much non-renewable recourses are used?
- How much waste is released to the environment after production?
- How much waste will be released to the environment after the product life cycle?

There are plenty of indicators that can be used to assess the environment impact under manufacturing environment; it should be based on the company product and company working process. One set of the general and comprehensive green indicators for sustainable manufacturing are developed by the Organisation for Economic Co-operation and Development (OECD) are illustrated in Table 7 for customized development based on different company's needs and constrains.

The detailed explanation and formulas regarding the calculations have been listed below as well:

- Non-renewable materials intensity=Weight of non-renewable resources consumed/Normalization factor
- Restricted substances intensity=Weight of restricted substances consumed/Normalization factor
- Recycled/reused content of material inputs=(Total weight of recycled material + Total weight of reused material)/Total weight of material inputs x 100
- Water intensity=Total water intake/Normalization factor
- Energy intensity=(Energy consumed in production processes + Energy consumed in overhead)/ Normalization factor
- Renewable proportion of energy consumed=Renewable energy consumed/Total energy consumed x 100
- Greenhouse gas(GHG) intensity=(GHGs released in energy consumption for production + GHGs released in energy consumption for overhead + GHGs released by transport used for business travel + Additional GHGs released from production process)/Normalization factor
- Residuals intensity (mass balance) =(Weights of all inputs + Weight of fuel consumed-Weight of all products)/Normalization factor
- Or: Residuals Intensity (Waste output) = (Weight of release to air + Weight of releases to surface water + Weight of releases to land + Weight of releases from landfills + Weight of transfers to

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disposal + Weight of transfers to treatment +Weight of transfers for recycling + Weight of transfers for energy recovery + Weight of transfers to sewage + Weight of additional GHGs produced + Carbon content of direct energy use) / Normalization factor

- Intensity of pollutant release to air = Weight of releases (from production processes and, if available, overhead) to air/Normalization factor
- Intensity of pollutant releases to surface water= Weight of releases (from production processes and, if available, overhead) to surface water/ Normalization factor
- Natural cover = Natural cover area/Total land area x100
- Recycled/reused content of products = Sum for each product (Weight of a product unit x Proportion of recycled content x Units produced) + (Weight of a produced unit x Proportion of reused content x Units produced)/ Sum for each product (Weight of a product unit x Units produced) x100
- Recyclability of products =Sum for each product (Weight of a product unit x Proportion of recyclable content x Units produced)/Sum for each product (Weight of a product unit x Units produced) x 100
- Renewable materials content of products = Sum for each product (Weight of a product unit x Proportion of renewable materials in product x Units produced)/Sum for each product(Weight of a product unit x Units produced) x 100
- Non-renewable materials intensity over product lifetime = Sum for each product (Weight of a product unit x Proportion of non-renewable content x Units produced)/Expected lifetime of product
- Restricted substances content of products = Sum for each product (Weight of a product unit x Proportion of restricted substances in product x Units produced)/Sum for each product (Weight of a product unit x Units produced)
- Intensity of energy consumption of products =Sum for each product (Average annual energy consumption of a product unit x Units produced) x Normalization factor
- Intensity of GHG emissions from products =Sum for each product (Average annual GHG emissions per product unit x Units produced)/Normalization factor

Social Assessment

As an important part of sustainable manufacturing, social responsibility has become more and more crucial for a company's image and its strategy to keep its talents. Besides, a social responsible manufacturing environment will have positive impact on employees' working moral as well as improving working efficiency.

Different organizations have proposed different code of conducts or guidelines for promoting social responsible behaviors, such as International Labor Organization's Conventions, the Universal Declaration of Human Rights, the United National Global Compact Principles (UNGC), etc. In addition, different companies have various ways to measure its social responsibilities. Social responsibility is a comprehensive concept meaning there is no clear boundary to define the right behaviors and unethical behaviors. In order to clearly measure the social responsible actions the manufacturing environment is taking, two audits are designed to comprehensively measure the extent of social responsible actions implemented under the manufacturing environment. One is the objective audit to measure visible actions or accidents that happen due to social responsibility in Table 8. The other is a subjective questionnaire designed for employees to estimate their feeling of company's social responsibilities in Table 9.

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Table 8. Social responsibility audit under manufacturing environment

Audit Items	Audit results
Clear Sign	
There is clear sign indicating different working or non-working area.	Yes/No/Not Complete
There is clear sign indicating the dangers or safety warning in working area.	Yes/No/Not Complete
There is clear instruction or brief warning regarding the machine or materials operation.	Yes/No/Not Complete
Protection Policy	
There is enough and functional fire extinguisher in different working or non-working area.	Yes/No/Not Complete
There is specific protection equipment for different profession, such as mask, protective cover, gloves, etc.	Yes/No/Not Complete
Working Environment	
Working environment is clean without excessive polluted liquid.	Yes/No
Working environment is clean without excessive solid waste.	Yes/No
Working environment is clean without unhealthy air circulating around the plant.	Yes/No
There is clear policy for working environment, regarding temperature, humidity for the sake of comfort.	Yes/No
There are enough and proper working tools.	Yes/No
There is clear policy for cleaning the working environment.	Yes/No
There is clear rule for proper working hour.	Yes/No
There is clear rule for not using child labor or forced labor.	Yes/No
There is clear rule against discrimination with regard to gender, sexuality, race, age, color and physical or mental disability.	Yes/No
There is proper space for employee's rest.	Yes/No
There is proper food plan and/or cooking equipment for employees.	Yes/No
There is clean water for employee.	Yes/No
There is proper accessible bathroom and/or cleaning room for employee.	Yes/No
Health Policy	
There is clear and comprehensive health plan for employees.	Yes/No
There is clear policy for working injuries recovery.	Yes/No
There is clear health plan of pregnancy for both women and men.	Yes/No
There is clear and proper policy for employee's rest, including statutory holidays and other statutory non-working time.	Yes/No
Other Policy	
The wage for employee is meeting legal requirements.	Yes/No
There is clear job responsibility.	Yes/No
Employees are free to make proper suggestions and complain.	Yes/No
There is clear policy against corruption or power abuse.	Yes/No

After the audit, the questionnaire Table 9 that will complement the results of the audit should be distributed to employees to investigate the social responsibility implementation situation.

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Table 9. Social responsibility questionnaire

Question	Answer
Warning	
1. Do you feel there is enough and proper instructions regarding how to operate the machine?	Yes/No
2. Do you get any proper and on-time warning before any accident happens?	Yes/No
Protection	
3. Do you have enough proper protection equipment when you are working?	Yes/No
4. Do you get proper instruction on how to use the protection equipment?	Yes/No
5. Do you always use the protection equipment when it is needed?	Yes/No
Working Environment	
6. Do you feel the working environment is clean?	Yes/No
7. Do you have any difficulty to access proper working tools?	Yes/No
8. Do you feel comfortable when you are working, due to working temperature and humidity?	Yes/No
9. Do you have enough time for rest?	Yes/No
10. Do you always work excessive hours?	Yes/No
11. Do you have difficulty to access bathroom?	Yes/No
12. Do you have difficulty to access clean water during work?	Yes/No
13. Do you have difficulty to eat during work on-site?	Yes/No
14. Do you feel discriminated during work?	Yes/No
Health Policy	
15. Are you able to access proper health plan from your company?	Yes/No
16. Are you able to claim injuries related to work on time?	Yes/No
17. Are you able to get proper health care after injuries related to work?	Yes/No
18. Are you able to get statutory leave?	Yes/No
19. Are you able to receive wage and proper health care during parental leave?	Yes/No
Other Policy related	
20. Are you able to make proper suggestions and/or complains to your supervisors or colleagues?	Yes/No
21. Do you witness any corruption and/or power abuse scenario?	
22. Do you feel that you have clear responsibility of your work?	Yes/No

STEP THREE: SUSTAINABILITY ANALYSIS

After collecting comprehensive information, the analyst should work with management team together to find out the current status and problems the organization is facing. Besides, it is crucial to uncover causes behind.

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Statistics Analysis

Based on the information gathered during measurement phase, different statistical tools can be used to analyze the current status of sustainability development in any manufacturing environment. The statistical analysis principles are:

- Calculate any descriptive measurement and/or any statistical inference
- Compare the number with standards if it exists
- Identify the extremes from measurement
- Figure out any trends included in the statistics

Compared with Six Sigma that is used for products deficiencies resolution, statistics analysis for sustainable manufacturing will be less complicated, since it involves a lot of subjective and single answer questions. And different size of manufacturing will involve different size of statistics to interpret.

Interpretative Analysis

Due to the nature of sustainable manufacturing, some factors are not directly related to statistics, there is need to interpret the hidden answers or observations that are resulted from incompliance of sustainability practice.

Some tools that are efficient to use are Cause and Effect Diagram and the 7 new Management and Planning tools, which can help to identify the causes for a specific event.

For sustainable manufacturing, there are 6Ms (Wikipedia, n.d.) used to identify the source of incompliance of sustainable manufacturing:

1. Machine (technology): Machine or technology might be source of incompliance. For example, if the machine consumes a lot of electricity or generate a lot of carbon dioxide.
2. Method (process): The work flow or work sequence might also case issues related to sustainable manufacturing. For instance, raw materials can be destroyed if they are not placed in a proper storage before it will be used.
3. Materials (Includes Raw Material, Consumables and Information): Usually raw materials will consist of some environmental pollutants or some materials are unrenewable. But incorrect information will also result in incompliance of sustainable manufacturing. For example, if there is no clear work guide for people who work in a mining or steel manufacturing environment, there will be high risks that employees will operate in a wrong way to lead to different incidents.
4. Man power (physical and mental power): Man power has played an important role in causing sustainability problems. For example, lack of labor will result in massive overwork. Child labor and women in manufacturing environment in developing countries get a lot of critics. Besides, mental health is one of the biggest issues that all the employers are dealing with in order to keep employees' efficiency and motivation.
5. Measurement (Inspection): The way to inspect the work environment has direct impact on how do we improve work situation. If the measurement is only focusing on product quality or production rate, then it might lead to heavy work load to employees.

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Figure 4. Kaizen EHS framework

6. Milieu/Mother nature: The natural environment surrounding employees can also have critical impact. For example, if the workers work in under mining situation, there will be health and safety issues remain under cover.

Not every factor will be contributing to the sustainability problem, but these 6 factors cover most of the causes. When organizations think of investigating roots of problems, it's better to have comprehensive investigation of all these factors in order to give suggestions for improvement.

STEP FOUR: SUSTAINABILITY IMPROVEMENT

Based on analysis results, there is need to set up improvement goals and specific actions to achieve sustainable manufacturing.

Kaizen EHS

Industries are aimed at maximizing profit, though investing in Kaizen EHS will not bring direct income for companies. Accidents and loss of natural resources and human resource will bring constant and hidden side effects for an organization. It is imperative to build EHS committee and have EHS policy to help manufacturing companies to improve production profitability. According to Kaizen principles "Plan-Do-Check-Act", Kaizen EHS framework (Figure 4) can be developed as "EHS Plan-EHS Implementation-EHS Inspection-EHS Correction".

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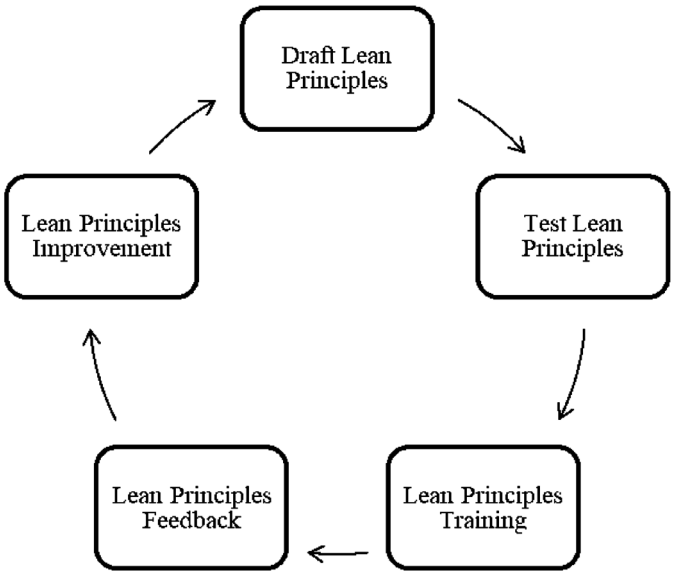
Figure 5. Kaizen lean cycle



During first phases EHS Plan, organization needs to set targets based on the analysis results which have shown the flaws of insufficiency of EHS policies. At this stage, there should be formation of EHS committee which consists of members from different functions.

For EHS Implementation, EHS committee will draft specific EHS policies based on the targets and any constrain. It should be validated against EHS international standards, such as ISO9001, ISO14000, and/or national or industrial standards. After policy making, there should be formal and continuous training for managers and employees in all departments since EHS target can be only achieved by involvement of all employees.

EHS Inspection is a periodical process to verify the actions that have been taken based on the EHS policy. It is better to have both internal and external auditors to audit the implementation activities. Auditors will do visual inspections with regard to actions of employees when they perform their work. Besides, auditors will verify actions based on documentation and interviews with employees and managers. At the end, auditors should generate report about the situation of implementation of EHS policy.

EHS Correction is a follow up process to improve what an organization has done and what can be added to correct the current situation. Both auditors and EHS committee members are deemed to join this action to continuously revise actions.

Kaizen Lean

Another important part to achieve sustainable manufacturing is to have Lean production system to reduce waste that will lead to waste of natural resource and accidents of operations due to non-streamlined activities.

Through Kaizen Lean cycle (Figure 5), organizations will draft their own lean principles that will meet their needs based on the analysis results. The principles cannot be applied directly before it is tested in a small range of production activities. The reason to test the principles is to validate and improve the

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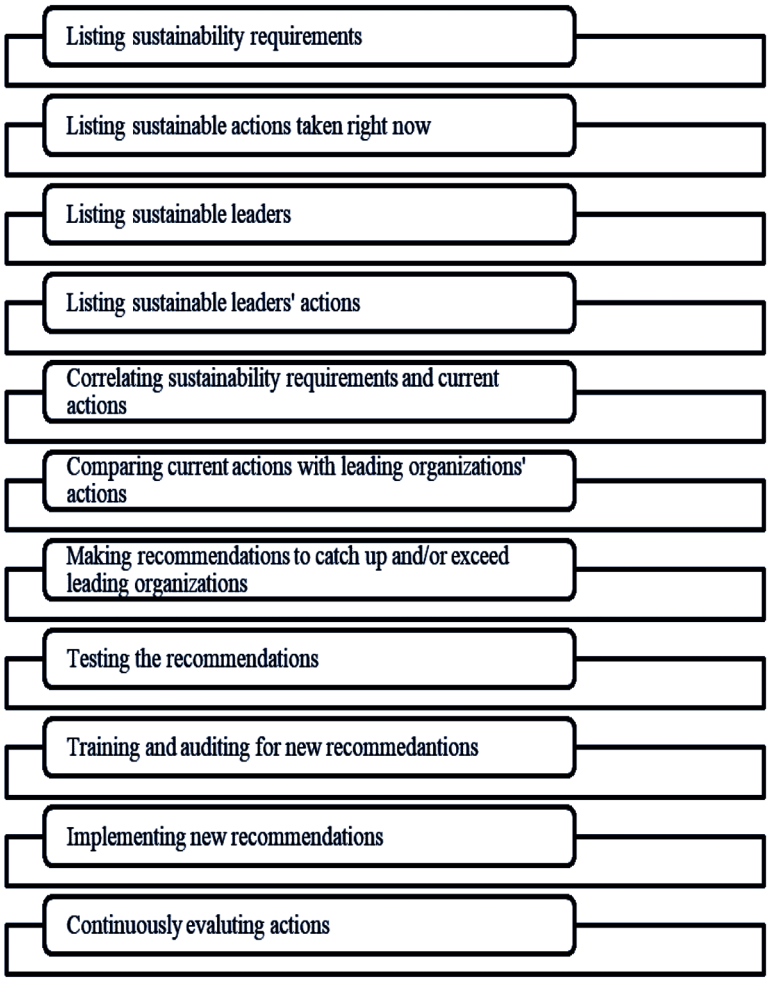
Figure 6. Sustainability leadership achievement roadmap



drafted principles to reflect its values on developing a sustainable manufacturing environment. After the validation and approval, there is need of training for all levels of employees to undertake these principles. Sustainability should be implemented as culture for the company, so the necessary training will give employees of all levels clear understanding of what the actions and reasons to implement the change. It is crucial to manage the changes and risks during the implementation phases. After the Lean principles are implemented, internal auditors are responsible for continuous auditing to get feedback of what has been done well and what needs to be improved. The feedback should be also from employees of all levels regarding their opinions of how comfortable and how valuable they feel for this new change. As essence of Kaizen, continuous improvement is always core of the changes; organizations should keep a dynamic mindset to adjust the Lean principles as it will appeal to the organizations' needs and status.

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Table 10. Achieving sustainable manufacturing leadership benchmarking

Gap Analysis	Sustainable Manufacturing requirement #1			
Gap #1	Sustainable action #1	Current Score #1	Leading Action #1	Leading Score #1
Recommendation #1				

STEP FIVE: ACHIEVING LEADERSHIP

As a way to continuously improve and learn from other organizations, there is need to compare current sustainability programs in plant with other competitors and industry leaders. It will help organizations to advance its practices and develop innovative programs to keep its leadership. There are a few steps (Figure 6) to shape its leadership by creating innovative sustainable practices. First, organizations need to list all the sustainability requirements and related actions taken right now. Second, organizations should analyze what the leading organizations' actions regarding to sustainability. Based on the analysis, organizations could make recommendations to close the gap between actions taken and target achieved among different organizations. While the recommendation should not be sitting only on desk, it should be tested before widely implemented. It is promising future for organizations to achieve leadership in sustainability. The House of Sustainability can be used as a tool to do such benchmarking.

The way to use the House of Sustainability is based on current situation and industry leaders' actions gap analysis (Table 10). Organizations will list sustainable manufacturing requirements, and the related actions taken in plant and its leading industry's actions. There will be score from 1-5 allocated to these actions to make rating based on advancement of this action. After understanding the gap, specific recommendations will be made for achieving leadership in sustainable manufacturing.

FUTURE RESEARCH DIRECTIONS

- **Validation of Framework Result in Long Term**: As nature of sustainability, it takes long term to display the benefits and results of sustainable actions. It is not feasible to implement all the actions to the case study target and acquire all results to validate the framework. In the future, there should be more case studies to adjust the suitability of the framework.
- **Expansion to Whole Supply Chain**: Besides, this thesis has given more weight to sustainable manufacturing, while in order to be competitive in the market, there needs to be collaboration among all stakeholders along the supply chain. The sustainability research has to be expanded from manufacturing to all functions of supply chain and integrate them together.
- **Suitability to All Industries**: As a powerful framework for sustainable manufacturing, it is necessary to validate its suitability in different industries since different industries have specific characteristics. Under this situation, some tools and/or metrics should be adjusted accordingly.
- **Summary of Measurement Metrics**: There are a lot of different metrics to measure sustainability performance from social, environmental and economic aspects. It is necessary to summarize these different metrics. It will help organizations to choose the most suitable one from all these metrics.
- **Investigation of Gaps Between Different Departments**: As a strategy for an organization, sustainability cannot be achieved by one person, there needs close collaboration among different

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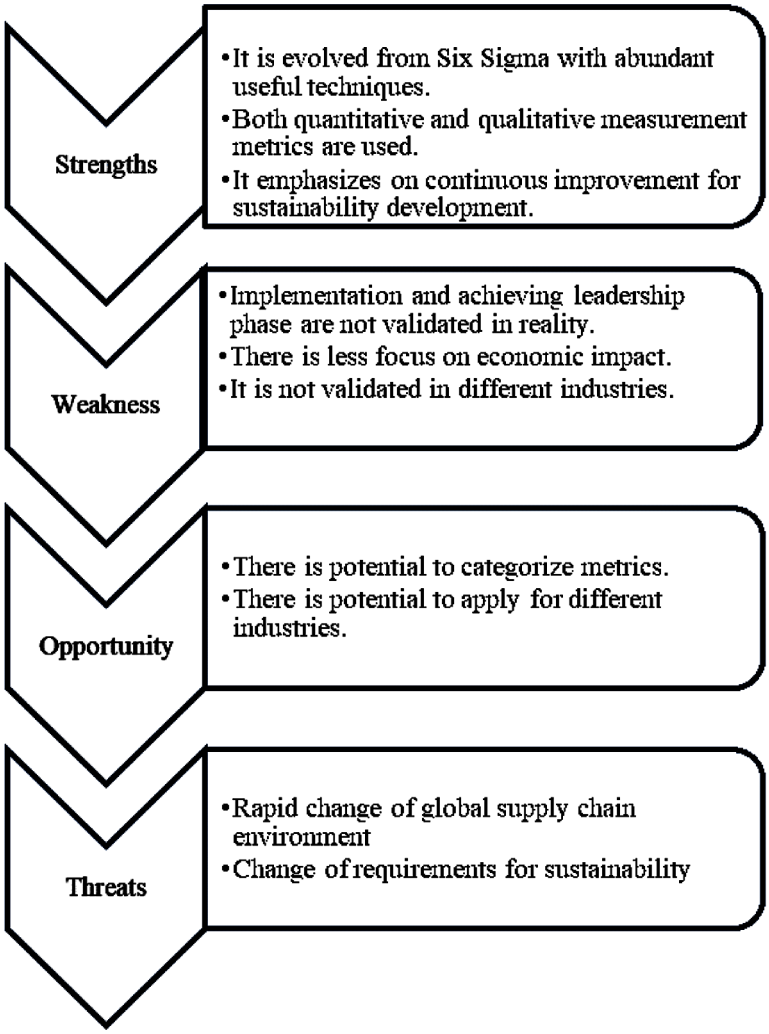
departments. The research of how to align the efforts among different departments seamlessly should be fully discussed in order to achieve leadership under supply chain environment.

- **Investigation of Interactions of Sustainability Measurement Metrics**: Sustainability measurement metrics are both subjective and objective at the same time. In the future, there is need to research if there is any interaction between these metrics and how these interactions can be controlled when organizations measure the sustainability performance.

CONCLUSION

Through SWOT analysis (Figure 7), the advantages and disadvantages of this thesis have been examined. This framwwork has evolved from Six Sigma and combined with all quality tools and concepts in order

Figure 7. SWOT analysis



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to improve sustainable performance. It has given weight to both quantitative and qualitative measurement to neutralize the bias.

Different from other framework, it showed progressive work from sustainable manufacturing to sustainable supply chain in order to achieve leadership in the market.

As for weakness of this research, there is lack of complete validation of the whole process since the outcome for sustainability development is a long term process. Additionally, this research has included all manufacturing processes, such as producing, packaging, movement, etc. Every process has its unique characteristics, it is necessary to distinguish them based on the sustainability requirements for each sub process. Nevertheless, this reseach has put more efforts on social and environmental criteria.

Talking about opportunities, there can be potential to categorize the measurement metrics. There are already a lot of publications and reports with regards to different types of sustainability measurement metrics. But there is no clear comparison of these metrics regarding its advantages, disadvantages and suitability for different industries.

While as for threats, the rapid change of global supply chain environment can impede the application of this method due to the complexity of global supply chain. What's more, the requirements for sustainability are changing as well, which can bring more challenges for organizations who want to continuously improve its sustainability performance.

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KEY TERMS AND DEFINITIONS

Achieving Excellence: It is similar as continuous improvement. It emphasizes that any organization should always look for area to improve.

Green: Philosophy that is strongly emphasized in manufacturing industry in order to reduce impact on environment.

Lean: It is Japanese philosophy that is generated from auto industry. It emphasizes that process in an organization should be fluid without any waste. Action will be taken only because of absolute demand.

Manufacturing: The process to assemble and/or fabricate final products using sub-components, machine, human resource, space, and other related resource.

Six Sigma: Problem solving practice that includes problem definition, problem measurement, problem analysis, problem solution, continuous improvement.

Supply Chain: The workflow that involves different stakeholders in order to produce satisfactory result-service, physical products.

Sustainability: The capacity to stay in the same level or better level for a long time period.

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Chapter 14
A Hybrid Approach Based on SERVQUAL, SERVPERF, and IPA for Measuring Transit Service Quality:
With Application for STM, Montreal

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ABSTRACT

The purpose of this chapter is to discuss the public perception of the quality of service in the public transit system in Montreal using a combination of analyses and surveys. The results are used to make recommendations to improve the STM and its perception. General guidelines of SERVQUAL with some additional questions that are more specific to the current social environment of the city are presented. A survey was conducted by asking 250 international graduate Concordia students to rate a series of statements based on the importance of the issue and how much they agreed with the statement, the results were analyzed using three methods: SERVQUAL, SERVPERF, and IPA. The improvement of timetable synchronization between different metro lines and buses is crucial, as well as the education of STM employees in terms of dealing with different ethnicities, languages, and backgrounds are found. The chapter is a rare outside look at the STM and how users perceive the quality of the service, as opposed to the usual internal studies done by the organization itself.

INTRODUCTION

The public transport sector in Montreal includes a metro and bus system (STM) as well as a borough train system (AMT). These are governmental organizations that aim to generate revenue as well as reduce congestion in the city.

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In 2010 Quebec had an estimated population of international students that exceeded 32,000 people (Economic Impact of International Education in Canada - An Update, 2016). The vast majority of these international students are in Montreal, the largest city in the province. Concordia University alone has over 6,500 students, it is a popular undergraduate and graduate school for students for all over the world.

International students generally tend to live close to the school they attend, which would lead them to rarely use public transport, or live in a more affordable area and using the public transit system often.

Service quality is the sum of costumer perception compared to the desired or expected performance of that service. It is assumed that the desired performance expectation is maximized as the city of Montreal will want its transit system to be as good as possible (under certain budgetary and technological constraints), this is especially important in a congested city and a world where "green" and eco-friendly measures such as transit systems instead of personal vehicles are being more and more encouraged by the worldwide population.

Service quality perception is based on previous experience using other similar services (in this case other public transit systems), as well as things they have heard about the service.

PROBLEM DEFINITION

While service quality has always been important, initially the objective of public transport was more focused on functionality and convenience than on customer approval ratings or quality perception. In recent years the focus has shifted more toward improving and ensuring a high level of service quality, this is done by benchmarking other, more successful public transit systems, optimization, and employee training that is more focused on service quality and empathy.

When it comes to service quality in public transportation there is not much research being done, most analysis is based on revenues (the more people take the metro, the more it is assumed that they are satisfied with the system).

In 2009 the Société de Transport de Montreal (STM) was awarded the American Public Transportation Association award for being the outstanding public transportation system in North America. This award is an impressive achievement, but technology is constantly changing at a very fast pace, not to mention that the user base is also constantly changing since there is a high turnover in the city caused by new students moving to one of the many universities served by the STM.

In this paper the authors ask themselves, how does the current generation of international students view the STM? Are they satisfied with the quality of the service that they receive? And what are the main areas that can be improved?

A survey was conducted with Concordia University international students about their usage and quality perceptions of the green metro line, the orange metro line, and the 165-bus route. The results were analyzed using SERVQUAL, SERVPERF, and IPA methods, then cross analyzed to see which of these metro and bus lines provided the highest quality for the rest to benchmark and which areas could and should be improved.

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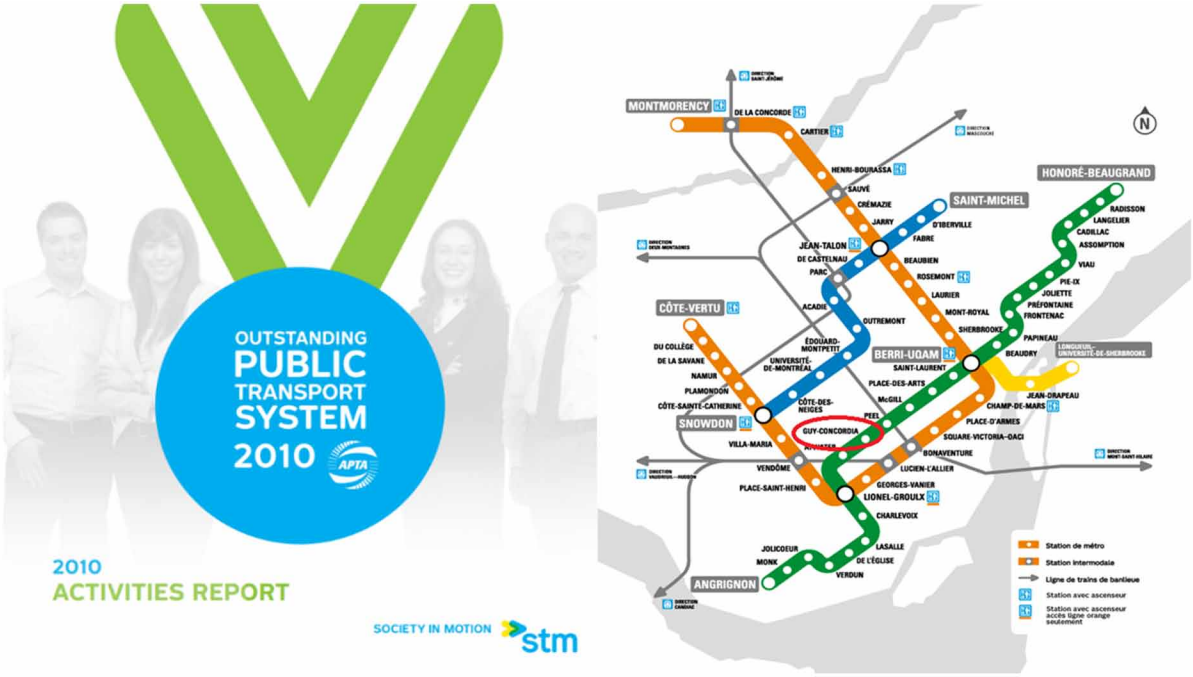
Figure 1. APTA award and metro map



LITTERATURE REVIEW

Research on service quality, and on public transit service quality is not a novelty. Plenty of research has been done in the field (Gronroos, 1982; Berry, Zeithaml, & Parasuraman, 1985; Parasuraman, Zeithaml, & Berry,1985; Zeithaml, Parasuraman, & Berry, 1985; Brady & Cronin, 2001). While this work certainly affects yhis chapter, the authors have to acknowledge that it does need some updating. Recent studies have been done in Ghana (Aidoo, E. N., Agyemang, W., Monkah, J. E., & Afukaar, F. K., 2013), Taiwan (Cheng, Y, 2011), Algiers (de Oña, J., Baouni, T., & de Oña, R. 2013) and Istanbul (Akan, P, 1995); Most studies seem to be done in developing countries where metros and buses are relatively new and are seeking to improve. Public expectations are very different now than they were 20 years ago, satisfaction is no longer simply based on efficiency, for example today sustainable development and environmental impact play a much bigger role in customer satisfaction (Too L., and Earl G. (2010). The present concept of service quality no longer applies due to the fact that people from different backgrounds and nationalities have different perceptions of what quality is (Randheer, 2011), this also applies to demographics (Lim, G.C., Bennett, R.R., and Dagger, T, 2008) different generations have different standards and demands (an elderly customer may be satisfied with the metro while a teenage may be unhappy with the lack of Wi-Fi). Customer satisfaction is also directly related to fares (Paulley, N., Balcombe, R., Mackett, R., Titheridge, H., Preston, J., Wardman, M., White, P.,2006), the more customers pay the more they expect from the service. Several standardized models exist when it comes to assessing service quality, but they are too broad and do not serve the purpose of judging public transit specifically. SERVQUAL cannot be used as is to truly judge the STM, it needs to be adapted, the same applies for SERVPERF and IPA. It is important to customize a model to match specific circumstances of the study context, generic ques-

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tions do not truly reflect the general opinion (Svensson, 2004). Customer satisfaction varies along serval factors such as demographics, income, education, climate, and social status, but up until recently it was assumed that all users are from the same location and have the same cultural background, SERVQUAL has to be adapted to include a culture element in order to be more meaningful (Karen & Boo, 2007). Randheer claims that culture is the main factor in customer satisfaction, and that customers of different backgrounds will have entirely different perception of a service. He claims that culture should be a main part of the study and improvements should be made based on the culture of the users and not a general definition of quality (Randheer, 2011).

Trompet, Liu, and Graham (2014) compared 14 public transit systems including the STM and found that the STM does not have a definition of service regularity. This means that the STM does not currently have a benchmark for what they consider trains and buses to be "on time" or "late". This is a worrying fact since it means that lines could easily be blurred and that the STM could accept delays more than other systems, for example in Brussels the STIB considers any trains that is over 2 minutes late "irregular", this is a hard benchmark to meet and would force the entire system to work well in order to do so.

There are no recent independent studies done on the STMs service quality (other than internal studies done by the STM itself and are not available for the public), this paper aims to bring to light public perception of Concordia university international students regarding the STM blue and orange metro lines, as well as the 165 bus using gap analysis (Meghna, V., and Ashish, V., 2013) and importance performance analysis, as well as comments taken from surveys which point out critical incident that lead to customer dissatisfaction (Edvardsson, B., 1998). This will help point out the current flaws of the STM and understand how the international community perceives our public transit system.

METHODOLOGY

This section will discuss the various methods used to analyze the data that the authors have gathered.

The methods used to analyze the data are SERVQUAL, SERVPERF, and Importance Performance Analysis (IPA).

1. SERVQUAL

SERVQUAL is a service quality measurement tool that is based on five dimensions: tangibles, reliability, responsiveness, assurance, and empathy. These are considered to be five dimensions that cover all that matters to customers or users when it comes to quality. It is important to understand what each of these dimensions means:

- **Tangibles**: Appearance and physical state of the environment, its employees, and to a certain extent its other users. This includes the design (how modern) of the environment and the hygiene and cleanliness of it. In this case this would mean the cleanliness of the stations, the employees and whether they look modern.
- **Reliability**: Ability to perform the service accurately and consistently. In this case this would be related to metro and bus timing accuracy and how often they break down.

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- **Responsiveness**: Willingness to help users and being able to provide good service. This relates to how well STM employees are willing to help users and whether or not they have the know-how to do so.
- **Assurance**: Trust in the service and its employees that they have the ability and knowledge to provide the service and handle any situation. This relates to how much people trust the STM and its employees to transport them from one point to another.
- **Empathy**: The care and attention provided to each individual user. Empathy in the STM is about whether or not to employees are courteous and if they seem to care about individual user problems or not.

In SERVQUAL a gap analysis is usually conducted, gap analysis is the comparison between the expected performance of a dimension or an item by the entity in charge (in this case the authors and the STM) and the user perception (in this case the survey responses).

Since the researchers do not have access to what the goals of the STM are, they assumed that they are aiming for perfection. This means that any positive statement was be given an expected score of 5 (strongly agree) as the target would be for the user to strongly agree that the service is very good.

A gap analysis was then be performed for each item on the survey in order to draw conclusions about what dimensions of the STM service are performing well and what needs to be improved.

Some elements were looked at based on age or gender to see if results change.

2. SERVPERF

SERVPERF is a service quality measuring tool that is based on SERVQUAL. It is based on the same 5 dimensions listed above. Fewer questions are usually asked in SERVPERF and it is done on a 1 to 7 scale instead of 1 to 5.

The main difference between SERVQUAL and SERVPERF is that the SERVPERF considers the importance of each statement, while SERQUAL gives equal importance to all.

This weighted approach gives the researchers a clearer picture of what dimensions or elements users care about and would help to avoid wasting valuable resources fixing or improving something that the user does not care about.

Usually weights are chosen by management but just like with SERVQUAL the authors do not have access to STM upper management so instead the weights are based on the section of the survey titles “importance of this issue to me”, this may be an even more beneficial way to see what needs improvement and what is satisfactory since it is based on what users or customers care about. For example, users may give the STM mobile app a poor approval score, but it may not be important to update the app if the importance score is low as they do not care about it, but if the importance score is high then it is crucial to update the app as it is considered to be very important by STM users yet they are severely unsatisfied with it.

Performance scores will be calculated using Importance factor x given score. This will give the authors a better idea about what is performing well as well as what is important to the user.

SERVPERF does not use gap analysis, scores are looked at and interpreted without being compared to expectations.

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3. Importance Performance Analysis (IPA)

IPA differs from SERQUAL and SERVPERF because is requires a two dimensional gap analysis. This means that it does not simply compare two values, instead it requires the creation of a chart where given scores are taken as the *x* coordinate and importance are taken as the *y* coordinate.

In IPA there is no expected performance, it is simply a chart that can be looked at and decisions on what to improve are based on what quadrant the item falls in.

Figure 2. IPA chart (Chang, 2011)

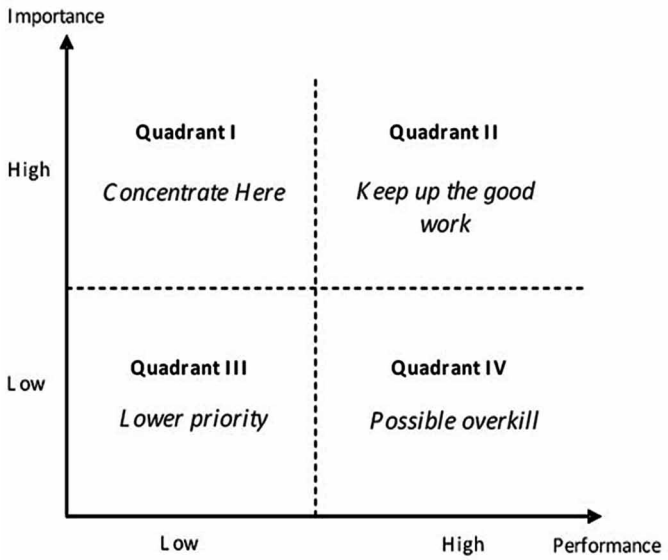

Table 1. Comparison between methods used

Method	Definition	Pros	Cons
SERVQUAL	Uses 5 dimensions to conduct gap analysis by comparing results to expectations. Gap = Expectation - Perception	Covers several areas. Gap analysis shows difference between expectations and perception.	Every situation is unique and sometimes more than 5 standard dimensions are needed.
SERVPERF	Uses same elements as SERVQUAL but also considers the importance of each element to the user, no gap analysis is conducted. Servqual = Perception x importance	Takes into consideration the fact that users care about somethings more than others, which helps prioritize.	Low perceptions and high importance may lead to the same score as high perception and low importance, this makes the data more difficult to read.
IPA	Uses two-dimensional gap analysis, using perception scores as the x axis and importance as the x axis.	Helps visualize what elements need to be improved, and where too much effort is needlessly being spent.	Does not take into consideration where we want each element to be on the chart.

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4. Justification

These three methods were chosen in order to make sure that there is no bias when it comes to the interpretation of the data. If results are similar in all 3 analyses then the authors can be certain of the performance of each item, if results are different then further analysis is need to look into why that is the case.

The three methods were chosen because they are different enough to let the researchers look at different aspects of the questions. SERVQUAL will let them see what items are performing poorly or well without considering the weight or important of that item, it will also let them compare each performance to a benchmark that they had previously set (in this case a perfect score).

SERVPERF allows the researchers to consider the importance of an item and its score is calculated by multiplying the importance and the user assigned score. The main pitfall of this method is that when multiplying the two results the researchers could end up in a situation where they do not know why a score is high, low, or average. For example; if an item ends up with a score of 8, it could be because the importance was crucial (5) and the given score was low (1.6) or vice versa, or any combination of two numbers that lead to getting an 8 as a final score. This issue is addressed by the next method.

IPA allows the researchers to visualize the importance and performance of each item, more importantly it also allows them to understand how an item is performing compared to how important it is, solving the issue they have with SERVPERF. IPA also helps to determine the areas that need to be worked on (high importance, low performance).

RESULTS AND DISCUSSION

The collected survey data points were tallied in an excel sheet and the results will be discussed in this section. The goal of these results is to compare the three systems (green metro, orange metro line, and the 165 bus), suggest improvements, and decide which one should be benchmarked by the others. Based on the results, threeof the statements on the survey were ignored as the users had little to no interest in these matters, this led to deceivingly low scores and would mean that the wrong areas would be focused on. The dismissed statements are: It is easy to carry my bike on the metro, I use carsharing, and I use bikesharing offers with the metro.

1. SERVQUAL

A gap analysis was performed for the SERVQUAL data on each line in question, the smaller the gap the better the performance. Statements were organized by gap from left to right, starting with the highest performing statements.

a. Metro, Green Line

The green line on the Montreal metro system serves the stations between Angrignon and Honore-Beaugrand. This line had the highest number of responses as it serves the Guy-Concordia metro station, which the majority of students use to get to the university.

The top performing categories are related to speed, efficiency, safety, and ease of access to information and ticket purchasing.

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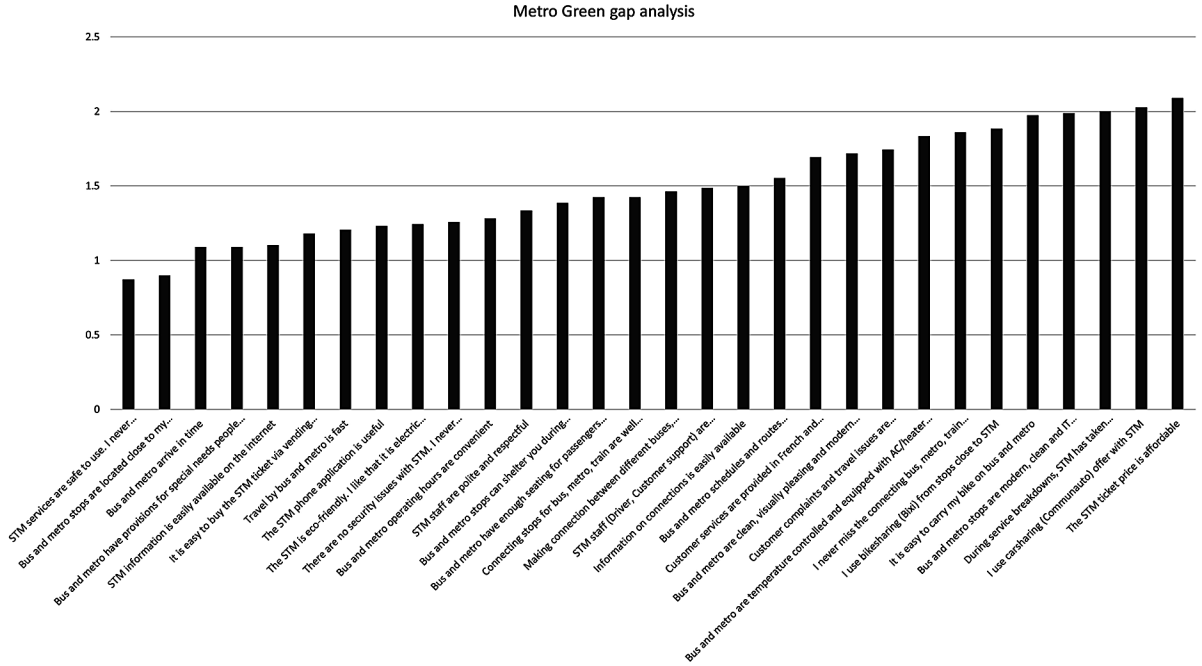
Figure 3. Metro green line SERVQUAL gap analysis



The poorest performing categories are ticket pricing, tangibles (physical appearance of the metro stations and the trains), the responsiveness of employees, and the synchronization between connections.

The ticket price issue is mainly attributed to the fact that students over the age of 25 do not get the student pricing for the monthly STM pass. The complaint here is that even though these students are over the age of 25 they are still international students that have to live on a budget and do not have an income.

The tangibles are an issue that is being worked on currently with the new trains being implemented on the orange line, and eventually on all lines.

Synchronization between connections could be fairly easily fixed by optimizing the system.

Employee responsiveness is a major issue that must be addressed, as it is not a simple fix, rather one that requires time and training and a broader more open mindset that is very hard to instill in older generations.

b. Metro, Orange Line

The orange line on the Montreal metro system serves all stations between Montmorency and Cote-Vertu. This is a popular line for Concordia students because it connects most of the city to the green line, making transport to the university from different parts of the island easier.

Accessibility to the metro stations is the most positive item here, as well as safety, metro punctuality and ease of access to information online.

Just like the green line, the main issues are related to timetable synchronization, tangibles, and responsiveness and in a way empathy (employees are not polite to non-French speakers).

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It is understandable that users on the orange line face issues with timetable synchronization since all of these people need to transfer to the green line on their way to the university, this means that they face daily line changes and it can get annoying if they constantly miss a train that had just departed before they arrived.

c. Bus, 165 Route

It is important to look at bus survey results since it is a large part of the STM but results can vary from those we've seen for the metro as they are two different services, bus stops are outdoors, and capacity and speed are different from the metro.

Surprisingly users are very satisfied with the punctuality of the bus, which is much harder to guarantee than the metro, but it is worth noting that most of the users are taking the bus from Guy and Maisonneuve which is where it takes off from, this means that they do not deal with delays while waiting for the bus as they are departing from its first stop.

The poorest performing category is missing connections, this could be explained by the fact that buses generally have more trouble sticking to schedule due to unexpected delays on the road, traffic lights, and people embarking/disembarking.

Employee responsiveness is another major issue since more people deal directly with a bus driver than they do in the metro where they may only interact with an employee once a month when they renew their passes. Ticket pricing is also a common complaint (expected as it is the same as the metro).

Tangibles are to a certain extent also an issue, especially temperature control as buses can get very hot and crowded during the summer and waiting for the bus is unpleasant in the extremely cold temperature of the Canadian winter.

2. SERVPERF

The SERVPERF analysis not only shows the performance of each category but also shows the importance of that category to the user. Again, statements are organized from left to right from best performance and importance to the poorest.

a. Metro, Green Line

Just like with SERVQUAL the same themes emerge here. The main complaints are regarding the price, responsiveness, tangibles and synchronization.

b. Metro, Orange Line

The usual trends appear yet again with SERVPERF results being very similar to SERVQUAL results for the orange line. One complaint that appears here and appeared consistently in the comment section of the survey is that STM employees were rude and unfriendly to English speakers and foreigners, especially the further out they get from downtown Montreal. This is an important issue that must be addressed as Montreal is a large, multicultural city that prides itself on welcoming people from all over the world, and the STM is a direct representative of the city.

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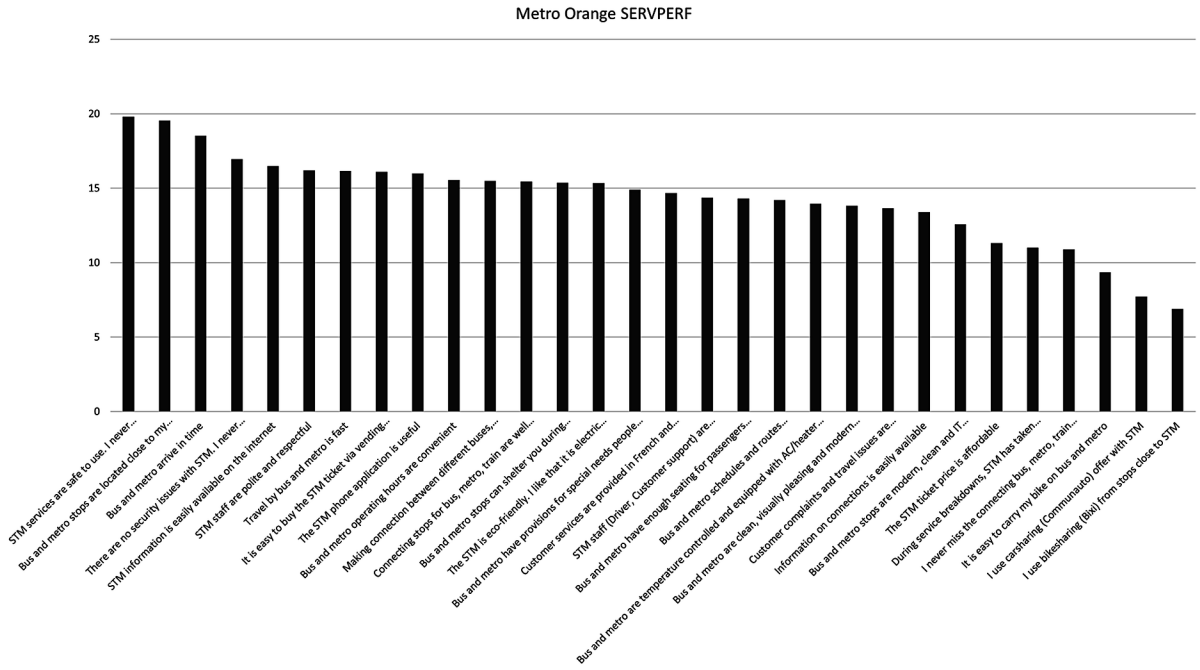
Figure 4. Metro orange line SERVPERF results



c. Bus, 165 Route

Bus stop locations are rated very highly here, since bus stops are more common than metro stations especially in more residential areas. Empathy, in the form of measures taken to accommodate people in need is highly rated as well here compared to the metro. Safety as usual is a consistently well rated category.

Very similar results to the previous section (figure 9) are found here when it comes to poorly performing categories.

One thing that is interesting, and it has come up in most figures in our analysis, is that while a couple of categories perform well, and a few perform badly, most categories are distinctly average. This could either be an indicator of consistency, albeit a consistency of average performances, or simply a lack of interest from the user (they do not care about the quality since it is a service that they use for a very limited time during the day).

SERVPERF in this case does not seem to contribute much when it comes to analysis of the performance quality since results are too similar to SERQUAL gap analysis.

3. Importance Performance Analysis (IPA)

Importance Performance Analysis (IPA) shows what factors should be worked on based on importance vs performance. Special attention will be paid to items that fall in the top left quadrant as they are considered important but not performing well. Data points on the chart are numbered and cross referenced to the excel sheet used to create the graph.

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a. Metro, Green Line

The poorest performing item is ticket pricing, employee responsiveness, and the physical appearance of the metro, are the main complaints. Timetable synchronization and temperature control are also some of the more pressing issues.

It is interesting to see that no data points fall in the bottom right quadrant which means that no resources are being spent on unimportant or trivial matters. This could be an indication of good management.

b. Metro, Orange Line

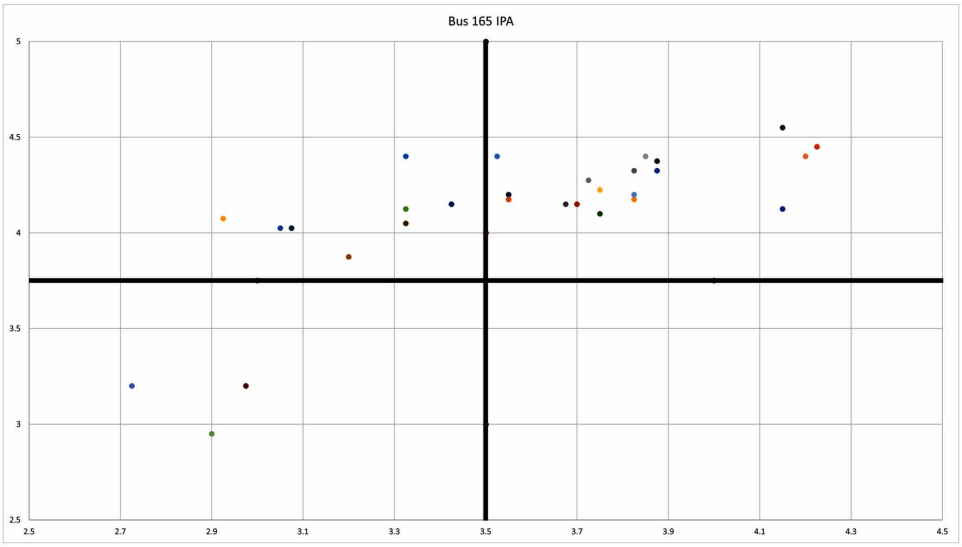
The orange line performs very impressively when it comes to the speed of transport on the metro, safety, and proximity of stations to where users live, all categories that users rate as crucial.

Just like the green line, the same complaints about important matters appear, the poorest performing item being timetable synchronization. Other poorly performing crucial items are ticket pricing, employee responsiveness, tangibles. Predictably there are more complaints about information about connections here because as mentioned before all these users have to switch to the green line at some point. Another minor complaint is a lack of number of seats available, this makes sense as the orange line is the most commonly used metro line in the city.

c. Bus, 165 Route

There seem to be more positive results for the 165-bus compared to the metro (more data points in the top right quadrant). The poorest item is timetable synchronization, the other main complaints are related to employee responsiveness and temperature control. It is interesting to note that the poorest performing elements here are not as important as those in the metro according to the users, the poorest performing elements are fairly close to the dividing line between the top left quadrant and the bottom left.

Figure 5. Bus 165 IPA results



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4. Comparison

While the analysis of the three separate systems is a good indicator of what aspects of the public transit system may or may not be performing well, comparing the three alternatives is the best way to try and improve those matters.

In order to compare the alternatives, the authors will use the IPA analysis for each line or route to determine which areas of the service muse be focused on. SERVQUAL scores will then be used to determine which of the three alternatives performs best in that particular category. Obviously some elements are common to all the metro and bus lines so common sense will be used in order to determine what can and cannot be benchmarked (for example, ticket prices are the same). Suggestions will be made based on this comparative analysis.

The best performing route of line for each category is highlighted in yellow.

First, the authors took a look at some of the high performing categories.

The highest performing category of the entire study is the proximity of orange line metro stations to where users live, the green line and the 165 bus also have high scores in this area.

Safety is also a high point; it seems few or none of the users have had any accidents or dealt with theft either on the metro or the bus.

Metro and especially bus punctuality is a positive, although this is explained by the fact that most of the users take the 165 bus from its original departure so there is little chance of the bus being late.

Buses seem to have better provisions for people with special needs (the bus does tilt down to accommodate people who have trouble getting on), while metros do not get an average score. Metros have stairs which make it more difficult for people with disabilities to navigate the stations. Reserved seats in buses are more obvious than the ones in the metro.

Figure 6. High performing categories

Item	SERVQUAL scores		
	Green	Orange	165
STM services are safe to use. I never encountered any accident	4.12820513	4.25	4.2
Bus and metro stops are located close to my place	4.1025641	4.28125	4.15
Bus and metro arrive in time	3.91025641	4.03125	4.225
Bus and metro have provisions for special needs people people women (e.g. children, elderly, disabled)	3.91025641	3.78125	4.15
It is easy to buy the STM ticket via vending machines at stations	3.82051282	3.8125	3.875

Figure 7. Poorly performing categories

Item	SERVQUAL scores		
	Green	Orange	165
During service breakdowns, STM has taken good arrangements for transfer	3	2.75	3.05
Bus and metro stops are modern, clean and IT equipped	3.01282051	3	3.325
Customer complaints and travel issues are resolved in a timely manner	3.25641026	3.4375	3.2
Bus and metro are clean, visually pleasing and modern modern	3.28205128	3.15625	3.325
Customer services are provided in French and English	3.30769231	3.5	3.425
I never miss the connecting bus, metro, train during transfer. They are time synchronized	3.14102564	2.65625	2.925
Information on connections is easily available	3.5	3.34375	3.55
STM staff (Driver, Customer support) are knowledgeable and always willing to help	3.51282051	3.40625	3.7
Bus and metro have enough seating for passengers	3.57692308	3.46875	3.825
Bus and metro schedules and routes information is available at stops. It is clear and easy to access easy to access	3.44871795	3.46875	3.875
Bus and metro are temperature controlled and equipped with AC/heater equipped with AC/Heaters	3.16666667	3.075	3.28125

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Finally, users seem to enjoy the fact that they can pay on the spot while entering a bus in order to use it.

The poorest performing category is the responsiveness of the STM, particularly on the orange line, to make arrangement for their users in order to get them to their destinations in alternative ways in case the metro breaks down. This is a problem and huge lines form at neighboring bus stops whenever the metro breaks down. Another issue is that information on metro breakdowns is unclear and the re-opening time is not usually given.

Responsiveness continues to be an issue with customer complaints, as well as how willing (or in this case unwilling) the employees are to help. The bus does get a decent score because there is a direct interaction with the driver who can help the user, unlike the metro where the only point of contact is the person selling tickets before the turnstiles.

The biggest complaint, for all three lines, is the synchronization of timetables. Users seem to miss their connecting buses or metros because of a lack of coordination between lines. They expect of be getting off one bus, crossing the street and getting on their connection, but that is not the case and most of the time they end up waiting, sometimes in harsh conditions, for the next bus or metro.

What makes it worse is that users are also not satisfied with the availability of information about connections or routes.

Tangibles such as how clean and modern the stations, buses, and trains are is also a poorly perming section. The STM is currently working on that (albeit slowly) by replacing the metro trains on the orange line and eventually the entire network. Some metro stations could use a facelift and especially more attentive cleaning.

Temperature control is also an issue, especially in a city of extreme weather.

Finally, a common complaint in the comments section as well as the scores is the fact that STM employees clearly favor people who speak French, suggesting that they are even rude to users that speak English.

DATA COLLECTION

The data used for the purposes of this paper was collected using a SERVQUAL inspired survey, with additional questions that serve the authors' purpose. The survey was made up of simple and positive statements about the STM, such as "the metro is clean" to which the user had to give a rating of 1 to 5, 1 being "strongly disagree" and 5 being "strongly agree". Users also had to rate the importance of each issue to them from 1 to 5, 1 being "not important at all" and 5 being "extremely important/crucial". Since all the statements used were positive the ultimate goal is to have users give a 5 rating or strongly agree with all the statements. The questionnaire survey is presented in Figure 6 below.

Since the survey was partly based on SERVQUAL, it had statements relating to tangibles, quality assurance, employee responsiveness, service reliability, and employee empathy. These dimensions were discussed in the previous section about the methods used. A few extra statements were included to be more specific to Montreal, the STM and modern-day public concerns. These include questions related to the culture of the city (bilingual), the weather and conditions of the city (whether or not stops shelter people from harsh winter conditions), safety, Montreal specific car and bike sharing services, and finally environmental concerns.

A comment section was included at the bottom of the survey in case the responders felt that any of their concerns were not addressed in the survey.

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Figure 8. Survey used to collect data

Age	
Gender	
Are you an international student?	
Do you own a car?	
What bus or metro do you use the most? (please specify bus number of metro line)	

Service Area	Importance of this issue to me (1-5)	Performance score for the bus/metro service (1-5)
Bus and metro are clean, visually pleasing and modern		
Bus and metro arrive in time		
Travel by bus and metro is fast		
Bus and metro have enough seating for passengers		
Bus and metro have provisions for special needs people (e.g. children, women, elderly, disabled)		
Bus and metro operating hours are convenient		
Bus and metro are temperature controlled and equipped with AC/Heaters		
It is easy to carry my bike on bus and metro		
Bus and metro stops are located close to my place		
Bus and metro stops are modern, clean and IT equipped		
Bus and metro stops can shelter me during rain/snowy weather		

Bus and metro schedules and route information is available at stops. It is clear and easy to access		
Making a connection between different buses, trains (AMT) and metros is easy		
Information on connections is easily available		
Connecting stops for bus, metro, train are well located and not too far		
I never miss the connecting bus, metro, train during transfer. They are time synchronized		
During service breakdowns, the STM has taken good arrangements for transfer		
The STM ticket price is affordable		
It is easy to buy the STM ticket via vending machines at stations		
STM staff (driver, customer support) are knowledgeable and always willing to help		
STM staff are polite and respectful		
Customer complaints and travel issues are resolved in a timely manner		
Customer services are provided in French and English		
STM information is easily available on the internet.		
The STM phone application is useful		
STM services are safe to use, I never encountered any accident		
There are no security issues with STM, I never had any issues related to theft		
The STM is eco-friendly. I like that it is electric or runs on biodiesel		
I use carsharing (Communauto) offer with STM		
I use bikesharing (bixi) from stops close to STM		

RECOMMENDATIONS

From the above analysis the authors can see that the bus system has more favorable scores and outdoes the both metro lines in out of 11 the 16 items that were looked at more closely. Users are happier with the performance of the 165 bus than they are with both the green and orange metro lines.

The simple recommendation to be made is that the 165 bus should be benchmarked by the green and metro lines, especially when it comes to employees' responsiveness and ease of use.

A more in depth look at the problems that people complain about gives the authors the following recommendations to make:

- Add a pay on the spot option for metros (just like at the bus entrance) right before the turnstiles.
- Update the STM app to show where the buses are in real time using GPS (the same way Uber shows where nearby drivers are).
- Increase metro staff in order to give users who have a problem a human contact to help them solve their problem.
- Hire, or train staff of sensibility and how to treat users regardless of ethnicity, background, or spoken language.
- Improve the synchronization of timetables; schedule all buses and metros as one system instead of treating each line individually.
- The bus system should be benchmarked by the metro system in order to improve customer satisfaction.

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CONCLUSION AND FUTURE WORKS

Montreal is a multicultural city that welcomes thousands of people from all over the world every year, this means that the opinion of these newcomers is important as they represent a large part of the population.

While the STM did win an award for their performance in 2009 they cannot rest on their laurels because we live in a world where technology constantly changes, and user expectations are always rising. The STM must adapt or it could cause harm to the general perception of the whole city.

Something must be done about the synchronization of different lines and routes; timetables should be treated as one harmonious system instead of scheduling every line individually. At the heart of is this is a supply chain problem where a transfer between one metro line and another, or one metro line and a bus can be treated like a transition between a supplier and distributor. In this supply chain problem the time between the supplier and distributor would be minimized (but not taken all the way to 0 as people have to move between one metro and another), and treated like an item that is being moved where the supply chain management would want the truck from the supplier to arrive, and unload right before the truck from the distributor departs, instead of the supplier truck arriving just after the previous truck had already left and the shipment having to wait on a loading dock needlessly due to an unoptimized system.

STM employees must learn to accept people from all over the world and treat everyone equally, especially in more residential areas on the end of the orange line where STM staff interact with fewer people from other backgrounds and end up with a bias towards locals and French speakers.

More light should be shed on the environmental impact of public transit instead of taking a personal vehicle as it seems like not many people take that into consideration when they choose a method of transportation.

Future studies should consider a broader audience and take a look at other public transit systems from around the world. The results in this study may look bad but people everywhere complain about metros and buses, the STM may not be as bad as it seems but in spite of that they should not be aiming to simply be better than others, they should be aiming to be as good as possible.

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Chapter 15
Supplier Selection Improvement Process in an XYZ Company Through DMAIC

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ABSTRACT

The existing supplier selection process of an XYZ company will be defined and mapped to understand the process characteristics and capabilities and then it will be analyzed to identify non-value-added activities. Corrective actions will be recommended to improve the supplier selection process for the company using DMAIC technique. It will aid in developing a competitive supplier base out of bulk suppliers available in the market that will result in competitive advantage over its peers and achieving the quality, cost, and service enrichment goals.

INTRODUCTION

A supplier now-a-days works as a second heart of the company while the buyer being the first heart and any company's success depends on the interaction between two of them which makes the whole process more intriguing and challenging for the buyer. Buyer must implement procurement strategy in a way that gives the best value for money and for that internal communication with experts and then negotiation and co-ordination skills with outside parties become very crucial as far as the company's profit is concerned.

A Buyer of any company has to have skills such as efficient planning, negotiation, purchase and delivery, management and presentation. But his most important task will be to form an effective supplier selection process and choose potential suppliers for the best interest of a company. The name is easy but the process itself is very complex as it comprises of many factors. The process is tedious and time-consuming and therefore very demanding, but each company has it and still they somehow find it hard to follow it properly and adding new suppliers to their list on a regular basis which ultimately affects their profit.

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Therefore, a proper supplier selection process becomes essential in accruing any company's profit scale.

BACKGROUND

It's essential to know the types of suppliers available in the market before understanding the importance of choosing a right supplier for a firm. There are mainly seven types of suppliers that a buyer needs to play with according to a specific need.

1. **Manufacturers and Vendors:** They research, develop and finally produce the product which is ready for purchase.
2. **Wholesalers and Distributors:** They buy in bulk from many vendors and supply larger quantities to government and other organizations directly.
3. **Affiliate Merchants:** They sell their products with the help of banner ads and a network of affiliates.
4. **Franchisors:** It is a business owner who gives license to an individual to develop own business which includes suppliers often at less price than an individual can get for himself or herself.
5. **Importers and Exporters:** They will buy products from manufacturers in one country and export them to a distributor in another country or vice versa.
6. **Independent Crafts People:** They will sell directly their manufactured products directly to retailers or end customers.
7. **Drop Shippers:** They are suppliers of products from single or multiple firms which will deliver directly to the buyer.

The company should not only receive right materials, in right quantity, at right time, with the right service and at the right price but also from the right source which is supplier. Multiple sourcing has replaced single sourcing in most cases now-a-days as it dwindles external risks. However, it depends on the size of the company and their needs. Choosing the right suppliers is vital in giving consistent rise to any business and it is a skill that needs to be developed and there are many methods available for it and have been used by purchase managers but to build a long-term relationship with the supplier is as important as taking few factors while analyzing the whole process.

The importance of having a proper supplier can be inexplicable in words but in-general it affects the whole manufacturing process and therefore the customer while affects manufacturer's image in the market.

Supplier selection process is a part of the procurement process and their job is to get required goods while supply chain is the required infrastructure to get those goods. Therefore, both are different to an extent but supply chain management can be considered as one of the responsibilities of a procurement team.

Supplier selection process eventually increases the value of a purchaser by minimizing purchasing risk if formulated and executed properly. There are many theories available for supplier selection. However, in present scenario, supplier selection and evaluation, both go hand-in-hand and therefore it requires patience and time along with strategy. However, it should be flexible in-terms of consumer demand which varies day-in-and-day-out which puts procurement team under tremendous pressure and expects them to modify themselves according to the market and that is the first rule in developing an effective supplier selection process.

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There are many supplier selection methods available in the literature such as Prequalification method, Multi-attribute decision making techniques, Mathematical programming model methods, Artificial intelligence methods, Fuzzy logic approaches and Combined approaches. Each of them has been used on various occasions as per the industry requirement and procurement department decision.

A. **Prequalification Method:** It reduces the sample size of suppliers from available suppliers. There are three types of prequalification methods available in supplier selection – Data Envelopment Analysis (DEA), Cluster Analysis (CA) and Categorical methods.
B. **Multi-Attribute Decision Making Technique:** Analytical Hierarchical Process (AHP), Analytic Network Process (ANP), Total Cost of Ownership (TCO) techniques, Technique for the Order Performance by Similarity to Ideal Solution (TOPSIS), Multiple Attribute Utility Theory (MAUT) and Outranking methods are part of MADM technique in solving supplier selection quandaries. These techniques can be used when different supplier selection criteria conflict with each other.
C. **Mathematical Programming Model Methods:** This technique only considers quantitative aspect of the problem as it optimizes results using Multi-Objective and Goal Programming models. It certainly gives freedom to choose different criteria to decision takers which is the biggest benefit of solving a problem of opting best suppliers for any company by this method.
D. **Artificial Intelligence Methods:** This method takes into account historical data and experience to solve complex supplier selection and evaluation problems with the help of Case-Based-Reasoning (CBR) Systems and Artificial Neural Network (ANN). This method demands a software and an expert who can use it at will to solve the problems.
E. **Fuzzy Logic Approaches:** A fuzzy decision matrix invented from ratings and weights of various factors in-form of linguistics values allows a decision maker to take a decision by defining closeness coefficient of each option and then determining the ranking order of all the available alternatives.
F. **Combined Approaches:** There have been many combined approaches used in the past by authors to give best possible solutions regarding the supplier selection problems such as Ghodsupour and O'Brien's developed integrated AHP and LP model to include both tangible and intangible factors in solving the problem.

The best possible method one should take into consideration, solely depends on attributes which a purchase manager takes into consideration while forming the process either qualitative or quantitative or both. Along with that, characteristics also matter a lot while finding a global solution such as strategic decision, multi-actors, multi-criteria, subjective criteria and the type of a supplier – stochastic or deterministic.

Supplier selection is a judicious selection of suppliers to survive in a fluctuating market and a strategic survey from 2005 to 2012 of 78 different papers suggest that the present trend in the industry is using combination of two or more methods to get the best results. Moreover, AHP was the most preferred among researchers along with multiple sourcing.

However, before selecting the best method to choose a supplier, it is necessary to consider all important supplier selection attributes or factors.

There are quite a few factors affecting the selection of optimal suppliers in procurement management. It is a time consuming and complicated decision-making process by taking into account various factors associated with it. Stanley and George (2001) presented supplier selection criterion model and it is very well-known.

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1. **Cost Criteria:** It is directly connected with the purchase and the most common cost related with any product is purchase, operational, transportation and additional taxes. Price and distribution cost affect cost criteria. Profit maximization can be achieved through cost minimization only in this case.
2. **Technical Capability:** It is very important when it comes to delivering high quality product or high-class service. This should be considered when a company is thinking about developing a new product or a technology. Moreover, it can be tracked and measured also with the help of many tools such as compliance with quality, production schedule of suppliers etc.
3. **Quality Assessment:** This is important both for company and suppliers if they want to maintain and improve quality standard of a product. This assessment can be done with the help of product development of suppliers and process improvement of suppliers along with production inspection at frequent intervals to an extent.
4. **Organization Profile:** The most suitable suppliers should have high organization power and decent coordination skills.
5. **Service Levels:** It takes into account delivery, lead time and ease of communication. It is evident that the good service given by the supplier will help in accruing the customer base as per the argument of Beamon (1999). In the 21st century, for a supplier to be selected, proper delivery schedule, shorter lead time and negotiation skills, need to have and further for a long-term relationship with the manufacturers.
6. **Supplier's Profile:** It considers history of the suppliers along with financial status, response of customers and performance history. In general, a good financial base, a good customer base and more experienced suppliers are chosen.
7. **Risk Factor:** Domestic supplier selection is less risky than global as the later considers geographical location of the supplier and political stability of supplier's country as both can sometime hinder the business between a manufacture and a supplier. It is vital to know that cost and quality are more dominated criteria in the supplier selection process over the years. However, cost is the most important factor because it affects the profit margins directly in business organizations as well as in material management.

DMAIC is a tool of the Six Sigma method which consists of five phases namely – Define, Measure, Analyze, Improve and Control. It is used to ameliorate current process.

Define stage includes a clear statement of the problem along with areas of improvement while Measure phase consists of data to enhance the process. Analyze stage focuses on finding the root cause of a problem and Improve stage sets eye on improving the process. In the control stage, the focus is on controlling the improved process for a long period of time.

All and all, DMAIC is a fact-based problem-solving technique, aids in improving process which produces output, not output directly.

In the selected problem of supplier selection, DMAIC can be used in a following manner by forming a question in each stage.

The following table presents the tools which can be used to solve the DMAIC problem in each stage.

The importance of DMAIC lies in a simple fact that it has a proper structure as it analyzes process carefully before trying to propose ideas related to improving the process. The other benefit is of having a data-driven approach to find solutions of a problem from beginning to end.

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Table 1. DMAIC stages introduction

Stage	Question
Define	What is the current focus of the supplier selection process?
Measure	How does the current process function?
Analyze	What are the problems in the current process?
Improve	Which are the areas of improvements?
Control	How the improved process can be controlled?

Table 2. DMAIC tools with stages

Stage	Tools
Define	CTQ, SIPOC diagram, Voice of the customer gathering, Stakeholder analysis
Measure	Data collection plan, Process flowchart, Value stream mapping, Measurement system analysis
Analyze	Fishbone diagram, 5W2H analysis, Regression analysis, Statistical analysis, Scatter plot, Hypothesis testing
Improve	Mistake proofing, Failure Modes and Effects Analysis (FMEA), House of Quality, Design of Experiments, Simulation software
Control	Control charts (Variable and Attribute), Control Plan

MAIN FOCUS OF THE CHAPTER

DMAIC consists of many techniques in each of its stage to solve the problem as shown previously and here in a problem of supplier selection process improvement, following table suggests that which methods have been used in each stage to solve the problem for an XYZ company.

All the findings presented here was gathered through personal meetings and later on via questionaries' which aids further aids in solving the problem.

Table 3. Techniques used in each stage

Stage	Techniques used
Define	CTQ Chart
Measure	Process Mapping
	AHP
	Bayesia Lab
Analysis	Cause-and-Effect diagram
	5W2H analysis
	Bayesia Lab analysis
Improve	FMEA
Control	Communication and co-ordination suggestions
	Control plan

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Define Stage: What Is the Focus of the Process?

In an XYZ company, for example, there are 'n' number of suppliers along with 'n' number of products which they deliver to their customers as per the orders at a certain frequency. In-order to deliver the order at right time, first, it is important to know about the product family of an XYZ company and related suppliers and then to focus on one particular product family's suppliers to get the research going.

This stage focuses on inquiring into the point of view of both suppliers (up-stream) and customers (down-stream). The most vital factor will be of finding the customer requirements and critical factors which have the most impact on the supply chain performance. It is indeed challenging as there are quite-a-few factors available and it varies from company-to-company as shown earlier.

Let's first look at the product family of an XYZ company and the percentage of suppliers attached to it with the help of a pie-chart. It is presented below.

Here, it can be clearly seen from the above chart that company has most suppliers of resale product family but we will focus on the plant suppliers which is about of six percent of the all current suppliers' of the company to get the research going and to find the factual information about the current supplier selection process of an XYZ company. The pie-chart shown above was given by the purchase manager of an XYZ company.

Figure 1. Supplier data pie chart

Figure 2. PR to PO process

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Before going into detail, it's vital to know the purchase requisition to purchase order issuance in an XYZ company which then will aid in expounding the capabilities and characteristics of the supplier selection process in this phase of the DMAIC methodology.

Here, the complete process of getting raw material from supplier to in-house has been clearly stated with the help of flow chart. The focus in the supplier selection process will be on three things – Bidding, Supplier Evaluation and Negotiation. Let's look at them in detail.

Bidding

The competitive bidding process gives the best quality and best service at the right price to a company and therefore it is mandatory. It should take place before the purchase order generation. It can be done electronically as well as manually. Now-a-days, it is done electronically in-order to give chances to maximum supplier to compete. This whole bidding process takes place under the supervision of a purchasing professional and other team members.

In-order to choose the best supplier for the firm, following rules should be kept in mind.

1. Each supplier should be given equal chance by providing them right information.
2. Each supplier should be given enough time to respond to a bid.
3. Quoted confidential information of a supplier should not be shared with other suppliers.
4. The total cost of ownership along with quality and service should be taken into consideration before making the final selection of a supplier in any case.
5. If an agreement exists with a supplier, then it is obligatory to convert PR into PO.

Supplier Evaluation

The main objective of the supplier evaluation is of dwindling the purchasing risk and increasing the overall value to the buyer. In-order to establish a long-term relationship with a supplier, an evaluation and qualification process' are must. Supplier qualification consists of meeting the technical, commercial and financial requirements of a purchaser. While supplier evaluation suggests of assessing the performance based on certain criteria over a period.

Here, supplier evaluation is done on the basis of cost, quality, service and flexibility. Here, only qualified suppliers can receive orders from an XYZ company and then they are evaluated.

Negotiations

The final decision will be taken by a purchaser of an XYZ company based on negotiation policies and then and then contract can be offered and signed. If the contract is in another currency than the buyer's country currency, then the case should be handled as per CFO's guidance of the company. Moreover, bigger contracts should be reviewed by a legal advisor to be in a safe position if anything happens while doing a business further with the supplier.

The buyer of an XYZ company can adopt few strategies for negotiation such as – Proper communication, Proper research on actual costs, Finding areas of mutual profit, Put references of their customers and playing the high/low quality game.

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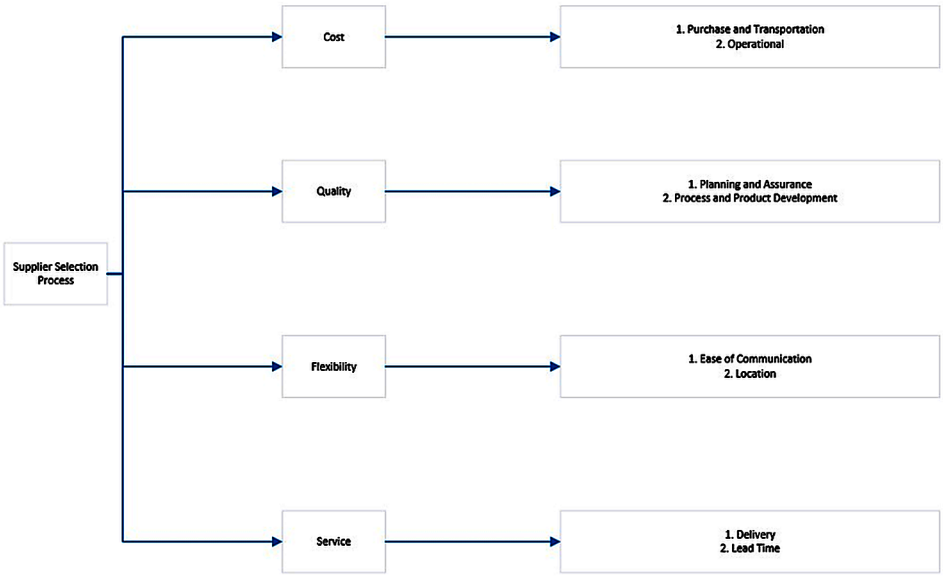
Figure 3. CTQ tree



Now, let's look at the four critical factors chose here in the supplier selection process – Cost, Quality, Service and Flexibility in detail. It has been presented with the help of Critical to Quality tree in this case in the define stage.

In-order to draw CTQ, first, we need to take a look at need and then we need to define drivers and after that CTQ requirements need to be written down which are easier to measure. In this case, the need is supplier selection process, drivers are Cost, Quality, Service and Flexibility. Let's look at CTQ requirements for each driver.

1. **Cost:** Purchase and Transportation along with Operational are the most dominant cost sub-factors which impact an XYZ company's supplier selection process.
2. **Quality:** As far as quality criteria is concerned, Planning and Assurance along with Process and Product development have been considered as the most dominant affecting sub-factors in the supplier selection and evaluation process.
3. **Service:** Most often delivery and lead time affect any supplier selection process as far as the service criteria is seen.
4. **Flexibility:** In the flexibility criteria, the two most important sub-factors given by the purchase manager of an XYZ company are Ease of Communication and Location.

It is vital to measure and analyze each criterion in detail. It will be done in the further stages to carry out further research along with to reach at a conclusion regarding supplier selection process.

Measure Stage: How Does the Process Function?

Here, in the measure stage of the DMAIC, company's current supplier selection process has been presented with the help of process mapping technique which does not take into account timings like Value Stream

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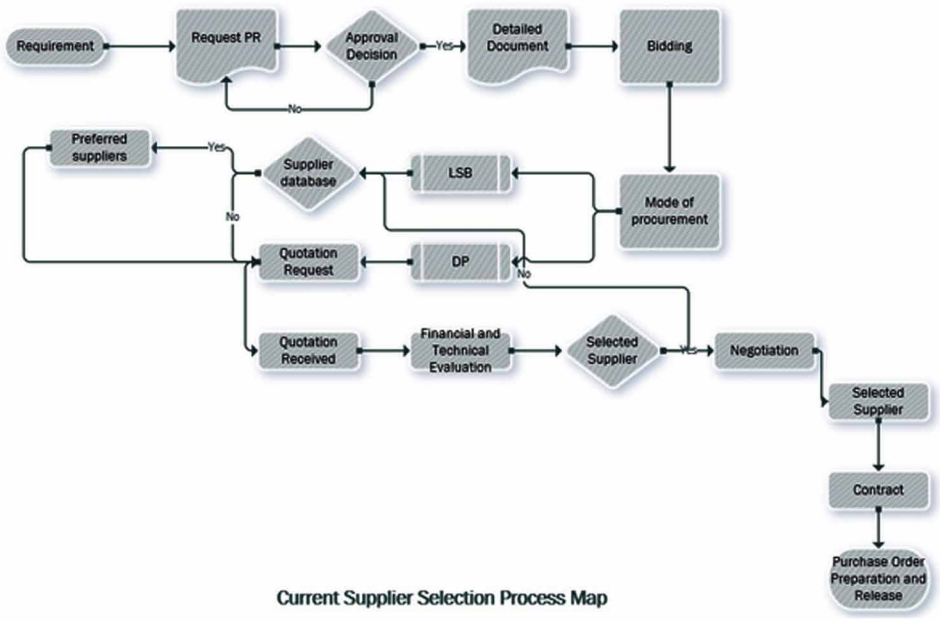
Figure 4. Current Supplier Selection Process



Mapping. Moreover, Analytical Hierarchy Process (AHP) has been introduced in this phase which was developed by Thomas L. Saaty in 1980 to allow complex decision making while dealing with complex problems which consist of both qualitative and quantitative attributes. Apart from these two, with the aid of Bayesia Lab Software and the purchase manager, the probabilities of getting each factor, positive and negative, has been effectively shown.

Let's look at all of them one-by-one.

Process Mapping

It is a tool which describes the flow of work visually. Here, the ongoing Supplier Selection Process has been shown in the below figure of an XYZ company. This mapping has been done with the help of Microsoft Visio software. It has some flaws which will be addressed later in the factual analysis. Here, in an XYZ company, the whole 'Procure to Pay' process has been done online and for that company uses own tool.

Analytical Hierarchy Process (AHP)

It has the capability of converting empirical data into mathematical models and the result can be analyzed as the higher the probability, the better chances that the alternative has to satisfy the final goal.

Here, first, the comparison matrix was provided to an XYZ company's purchase manager to fill it up by using fundamental Satty's scale for pair-wise comparison.

Comparison matrix provided:

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Table 4. AHP comparison matrix

	Cost	Quality	Flexibility	Service
Cost	1			
Quality		1		
Flexibility			1	
Service				1

Table 5. Satty's scale

Numerical Values	Verbal Term	Explanation
1	Equally important	Two elements have equal importance.
3	Moderately more important	Experience or judgement slightly favors one element
5	Strongly more important	Experience or judgement strongly favors one element
7	Very strongly more important	Dominance of one element proved in practice
9	Extremely more important	The highest order dominance of one element over another
2,4,6,8	Important intermediate values	Compromise is needed.

Satty's Scale

Comparison Matrix Received

Here, suppliers would have been chosen according to their composite weights after calculation of the priorities and then the best one would have been chosen. That table has been shown in the factual analysis section of the measure part. However, the main goal of this study is to assess based on the predetermined standard method.

Bayesian Networks

Today's deep interest in analytics, tell us to relate Bayesian Networks to understand statistics and then compare it with data mining. There are multiple reasons or motivation available for using Bayesian

Table 6. Received AHP comparison matrix

	Cost	Quality	Flexibility	Service
Cost	1	2	4	5
Quality	½	1	2	4
Flexibility	¼	½	1	2
Service	1/5	1/4	1/2	1

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Table 7. Cost node given

Probability – High	
Probability - Low	

Table 8. Quality node given

	P(Q) - Good	**P(Q) - Bad**
Probability Cost – High		
Probability Cost - Low		

Networks and we could approach it in the form of machine learning, probability theory or knowledge management but eventually it really depends on the end user that how it is possible to relate it with the objective.

Bayesian Network can be used basically with the help of nodes and links. Here, in this case, there are four possible nodes – Cost, Quality, Flexibility and Service. Now, it is more realistic to use probability theory here as the purchase manager was provided below table to fill it up from his experience that what the purchase manager of an XYZ company thinks about having the cost high or low and likewise many different combinations from a supplier. There were 5,000 such observations were generated from the Bayesia Lab software using the purchase manager's given probability values. Let's look at all of them in detail.

Nodes: Cost (Table 7), Quality (Table 8), Flexibility (Table 9) and Service (Table 10)

Here, in this case, cost being the most important criteria, it has been connected with three other nodes and then quality has been connected with flexibility and flexibility has been connected to service attribute. All of these decisions made after an interaction with an XYZ company's purchase manager based on what works in an XYZ company.

It is vital to know that Bayesia Lab software works on the uni-directional principal.

Here, the response recorded from an XYZ company's purchase manager has been presented below.

Cost: See Table 11

Table 9. Flexibility node given

	P(F) - Yes	**P(F) - No**
P(C) – High & P(Q) - Good		
P(C) – High & P(Q) – Bad		
P(C) – Low & P(Q) - Good		
P(C) – Low & P(Q) - Bad		

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Table 10. Service node given

	P(S) - Proper	P(S) - Improper
P(C) – High & P(Q) – Good & P(F) – Yes		
P(C) – High & P(Q) – Bad & P(F) - Yes		
P(C) – Low & P(Q) – Good & P(F) - Yes		
P(C) – Low & P(Q) – Bad & P(F) - Yes		
P(C) – High & P(Q) – Good & P(F) – No		
P(C) – High & P(Q) – Bad & P(F) – No		
P(C) – Low & P(Q) – Good & P(F) – No		
P(C) – Low & P(Q) – Bad & P(F) – No		

Table 11. Cost node received

Probability – Yes	**66.969**
Probability - No	33.031

Flexibility: See Table 13
Service: See Table 14
Quality: See Table 12

Now, an analysis will be carried out in the factual analysis part in the analysis stage which will give an idea about the dependency of one factor on other. The tools which will be used from the Bayesia Lab software for the analysis part will be entropy test and target mean analysis.

Table 12. Quality node received

	P(Q) – Good	P(Q) - Bad
Probability Cost – Yes	69.426	30.574
Probability Cost - No	53.194	46.806

Table 13. Flexibility node received

	P(F) - Yes	P(F) - No
P(C) – Yes	79.967	20.033
P(C) – No	55.352	44.468

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Table 14. Service node received

	P(S) - Proper	P(S) - Improper
P(C) – Yes & P(Q) – Good & P(F) – Yes	88.759	11.241
P(C) – Yes & P(Q) – Bad & P(F) - Yes	84.662	15.338
P(C) – No & P(Q) – Good & P(F) - Yes	64.790	35.210
P(C) – No & P(Q) – Bad & P(F) - Yes	47.833	52.167
P(C) – Yes & P(Q) – Good & P(F) – No	85.427	14.573
P(C) – Yes & P(Q) – Bad & P(F) – No	75.553	24.447
P(C) – No & P(Q) – Good & P(F) – No	35.897	64.103
P(C) – No & P(Q) – Bad & P(F) – No	12.896	87.104

Analyze Phase: What Are the Problems?

After defining the problem in the define phase clearly and having known the measurement criteria in the measure phase, DMAIC comes to analyze the problems and there are many tools which can be used to analyze the existing process so that it can be improved further in the improve phase and then can be controlled in the control phase for a longer period of time.

Those tools have been discussed earlier before having a look at the factual findings. From all of those mentioned in the analysis phase, here, 5W2H method and Cause-and-Effect diagram have been selected along with Bayesian Network Analysis with the help of Bayesia Lab software.

5W2H aids in having as much as best possible solutions while cause and effect diagram gives the best possible solution. In-order to use both the methods, brainstorming is needed.

All and all, this phase of the DMAIC methodology, tells us which are the factors that affect the above defined attributes in the Supplier Selection Process – Cost, Quality, Flexibility and Service. Moreover, it adds value while finding and eliminating the gap between current and expected future results.

5W2H

In-order to generate the ideas for improvement of a Supplier Selection Process, with the help of brainstorming and having the acronym of Why, What, Where, Who, When, How and How much, 5W2H is

Table 15. 5W2H method

Acronym	Issue	Question
Why	Purpose	Why is it a problem?
What	Symptoms	What's wrong in it?
Where	Place	Where does the problem take place?
Who	Involvement	Who are involved in it?
When	Time	When was the problem found?
How	Solution	How the situation can be improved?
Howmuch / Howmany	Solution level	In what measure it can be improved?

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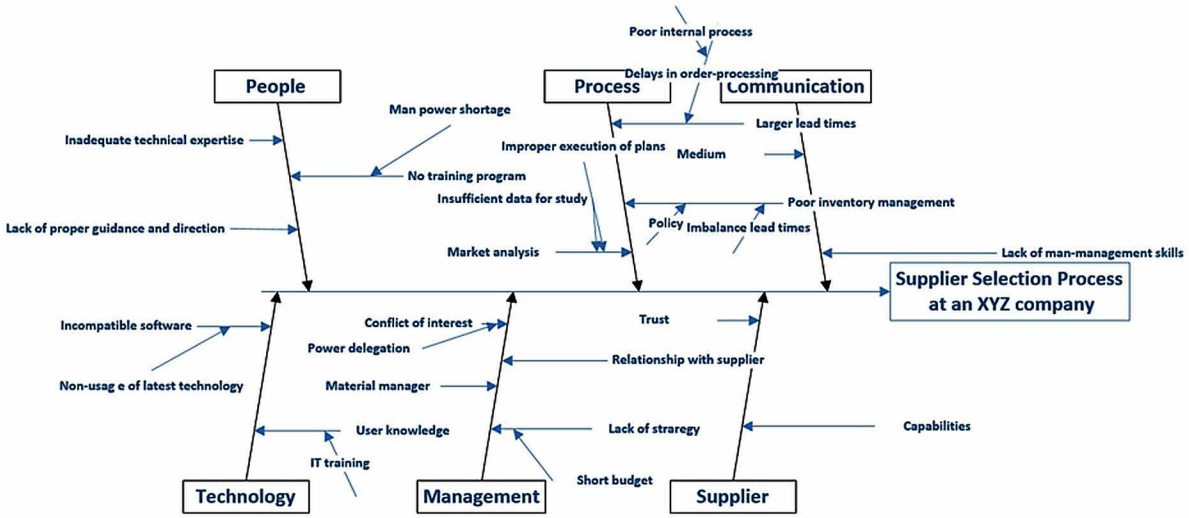
Figure 5. Cause and effect diagram



used which eventually helps in getting the best possible solution as and when working with the Cause and Effect diagram.

Let's understand 5W2H with the help of issues and then related questions.

Cause and Effect Diagram

On the other hand, this method uses either 5ME (Manpower, Machine, Method, Material, Measurement and Environment) or 4P (Policy, Procedures, Plant, People) to give the best possible solutions while doing the brainstorming. It will be presented graphically in the factual analysis section of the chapter.

But before implanting both these methods, it is important to list out problems which were found out while doing observation and in interview interactions.

- Technical department's inability to generate proper forecasting and thus material planning
- Technical department's infeasible and rigid criteria for a supplier selection
- Technical department's biasness in the supplier selection process
- There is a lack of advanced marketing analysis to commence the supplier selection process
- Market intelligence team's inability to use market resources fully.
- Lack of personal meetings arrangement with the suppliers at the time of negotiation.
- There are no survey strategies adoption before finalizing a supplier.
- IT department's inability to generate supplier category development before making a database.
- Direct purchases sometimes skip transaction recording.
- Delay in process in-case of preferred suppliers' negative response in giving expression of interest.
- Limited criteria for evaluation after receiving quote from suppliers
- Technical team's time consumption in making technical evaluation of suppliers
- Procurement team's adoption of ineffective tools of communication with the suppliers

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Improve Phase: What Can Be enhanced?

The main objective of this phase to implement a selected solution after finding risks associated with it. Here, Failure Mode and Effects Analysis has been selected for the same which is explained in brief below.

FMEA basically follows 10 steps to identify failures, effects and risks of a process, and then finds ways to reduce or eliminate problems.

Step 1: Review the selected process
Step 2: Brainstorm potential failure modes
Step 3: List out potential effects associated with each failure mode
Step 4: Assign a severity ranking to each effect
Step 5: Assign occurrence ranking for each failure mode
Step 6: Assign detection ranking for each failure mode
Step 7: Calculate Risk Priority Number (RPN) for each effect

Risk Priority Number = Severity*Occurrence*Detection

Step 8: Rank the failure modes for action
Step 9: Propose actions to remove or reduce the high-risk failure modes
Step 10: Calculate the resulting Risk Priority Number

The whole Failure Mode Effects Analysis chart will be presented in the Factual Analysis section of the chapter but before that it's imperative to know about improvement ideas gathered during interview interactions and related discussions in an XYZ company.

- Technical department has to generate proper forecasting and thus material planning with the help of superior individuals and tools available in the market. Forecasting strategy has to be reviewed quarterly or every six months to do the forecasting properly.
- Technical department has to have pragmatic and flexible criteria for a supplier selection process as some criteria were not allowing enough suppliers to enter in the supplier selection process earlier.
- Technical department should avoid biasness in the supplier selection process as a result of that there were some problems between technical and PR team.
- There should be a team of professionals to conduct marketing analysis to commence the supplier selection process which can help select the best suppliers available in the market.
- Market intelligence team must use market resources fully.
- There should be proper personal meetings arrangement with the suppliers at the time of negotiation.
- There must be survey strategies adoption before finalizing a supplier.
- IT department has to develop supplier category development before making a database.
- Direct purchases sometimes skip transaction recording therefore it must be avoided from the whole process or needs to monitor carefully.
- Delay in process in-case of preferred suppliers' negative response in giving expression of interest.
- Limited criteria for evaluation after receiving quote from suppliers
- Technical team's time consumption in making technical evaluation of suppliers
- Procurement team's adoption of ineffective tools of communication with the suppliers

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Table 16. DMAIC Stage with Solution

Stage	Activity
Define	Define process characteristics and attributes
Measure	Measure current Process Map
Analyze	Analyze problem areas
Improve	Suggest improvements and improved process maps
Control	Suggest control methods

- There must be proper evaluation period given to the technical department for technical evaluation of suppliers from the upper management.
- Letter of Intent document is same as of contract therefore a duplication of activities needs to be avoided to make the process faster.
- There should be a forum available on the company site so that the suppliers can get general information regarding pervious suppliers of an XYZ company.

Control Phase: How to Process Can Be Controlled?

This is the last phase of DMAIC methodology after implementing improvements. Therefore, there should be a method by which it can be controlled for a longer period of time and that standard method is developed and implemented in the control phase. The standard method needs to monitored and improved time to time.

Now, here in the case of an XYZ company, it is clearer as per the top management's feedback that it has less control on overall process. There was significant delay in the process along with least experienced professionals who were handling the whole process and as a result of that the whole supplier selection process was not helping the company

SOLUTIONS AND RECOMMENDATIONS

In the factual analysis part of the chapter, the factual findings will be analyzed and discussed in detail. The following table represents what will be done in each stage of factual analysis part of the DMAIC methodology.

Let's look at each stage in detail in this part.

Define

Here, in the define stage of the factual analysis part of the chapter, CTQ tree has not once again been presented as it has already set the direction.

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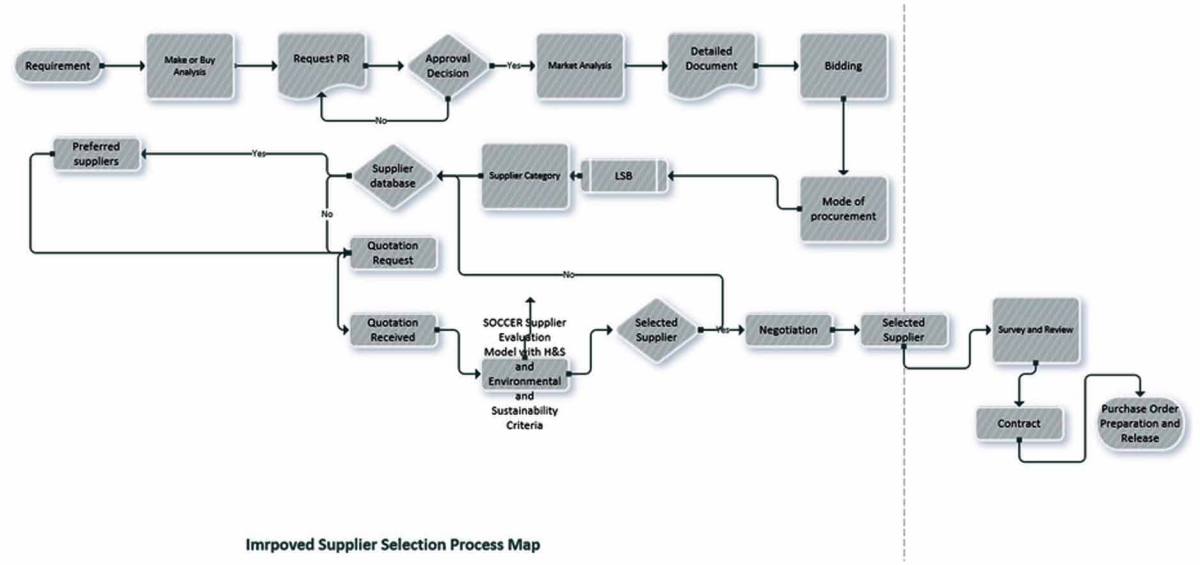
Figure 6. Improved supplier selection process map



Measure

While in the measure stage of the factual analysis part, improved process map of the supplier selection process of an XYZ company has been presented along with the results of the Analytical Hierarchy Process.

Based on the comparison matric received from the purchase manager of an XYZ company and now, after doing all the calculations related to Analytical Hierarchy Process, the final weights of the evaluation criteria have been presented below.

Table 17. Final weights of evaluation criteria in AHP

Criteria	Weight (%)
Cost	45.55
C1 Purchase and Transportation	75.10
C2 Operational	24.90
Quality	25.90
Q1 Planning and Assurance	17.00
Q2 Process and Product Development	83.00
Flexibility	12.95
F1 Ease of Communication	87.60
F2 Location	12.40
Service	12.13
S1 Delivery	83.00
S2 Lead Time	17.00

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This proves that cost is the most important attribute among four in the supplier selection process of an XYZ company currently while quality is at the second place and flexibility and service factor follow it. Cost contributes nearly half of the percentage of all the factors considered for the supplier selection process of an XYZ company currently which is somewhat pragmatic and expected.

Analyze

Here, in the analyze section, 5W2H and cause-and-effect diagram along with Bayesian Network analysis will be presented which will tell us more about the problems in detail to carry out improvements in such a manner that it can be controlled for a longer period in the following two stages.

5W2H

This tool will aid in understanding the whole supplier selection structure of an XYZ company in-depth.

Why

Discussion – Purpose
Question – Why is it a problem?

An XYZ company's purpose behind enhancing their current supplier selection process as follows:

- In-order to minimize or stop human interventions.
- In-order to remove trivial activities from the whole supplier selection process as much as possible.
- In-order to develop a competitive supplier database and strategy for the future usage.

What

Discussion – Symptoms
Question – What's wrong in it?

An XYZ company's professionals find following symptoms which inspire them to improve their current supplier selection process.

- There is a lack of marketing analysis at the beginning.
- There are ineffective tools of communication used during the important stages of the supplier selection process.
- There is a biased approach in the current supplier selection process.
- There are important criteria missing in the supplier evaluation process.
- There is no survey strategy for the selected supplier before handling a final contract.

Where

Discussion – Place

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Question – Where does the problem take place?

The above discussed problems arrive at the following stages of the current supplier selection process of an XYZ company.

- The problem takes place before the bidding stage as there is no proper marketing analysis done as in whether to make it in-house or purchase it from outside.
- The problem arises before making a supplier database as there is no supplier category development currently.
- The problem takes place while evaluating suppliers as there are not enough criteria taken into consideration currently.
- The problem takes place before giving a contract to the selected supplier without utilising any survey strategy to check their background.

Who

Discussion – Involvement
Question – Who are involved in the whole process?

Usually, the following departments' professionals are involved in the supplier selection process of an XYZ company currently.

Technical, Financial, Procurement, Legal and Information Technology

When

Discussion –Time
Question – When was the problem found?

- The problem arises while estimating cost as there is no mention of Total Cost of Ownership. Total Cost of Ownership is a financial estimate aiding buyers and owners deciding the direct and indirect costs related to a specific product or a system.
- The problem arises before making a database as currently there are no supplier categories available in the system.
- The problem arises in the bidding stage as there is no Express of Interest letter provided before the quotes request from the suppliers.
- The problem arises while releasing Purchaser Order via mail as sometimes it can delay the whole process.
- The problem arises while finalising negotiation as there is no survey strategy and personal meeting or video conference involved during the whole process with the selected suppliers.

How

Discussion – Solution
Question – How it can be improved?

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- SOCCER evaluation model must be used for the evaluation along with health and safety and environment and sustainability criteria.
- Direct purchase should be avoided as much as possible as it is all about manual transaction.
- There must be experts in doing proper market analysis and using market resources fully.
- There must be effective use of communication tools going forward other than ordinary mails to make the whole process smoother, faster and reliable.

How Much/How Many

Discussion – Number of solutions
Question – Howmany possible solutions are there for the current problems?

- An XYZ company should adopt standardized evaluation and measurement method to churn out possibly the best suppliers available in the market.
- There must be simplification in the selection process avoiding rigid criteria and biasness to a certain extent.
- Letter of Intent needs to be avoided as both contract and LOI are same, just to remove duplication of activities and save time.

Cause and Effect Diagram

Here, in the cause and effect diagram, we have six types of sources – People, Process, Communication, Technology, Management and Supplier. Each cause has its attached sub-cause which directly or indirectly affects the supplier selection process of an XYZ company. The whole cause-and-effect diagram for Supplier Selection Process in an XYZ company has presented below.

Let's look at each problem source in detail to gain understanding about from where the problem emerges actually and how it can be improved in the next stage and then can be controlled in the control stage of the DMAIC.

People

As far as the people are concerned then there can be three causes which are certainly affecting the supplier selection process -inadequate technical expertise, lack of proper guidance and direction from the upper management and ineffective training program which can be due to man power shortage.

Due to inadequate technical expertise, current employees working in the company set rigid and infeasible criteria which restrict few suppliers to enter into the bidding process. Therefore, it is mandatory for the upper management to guide them properly and in the right direction which is not happening now and for that they have to create effective training programs and which they are unable to because of lack of man power in the upper management due to restricted budget.

Process

As far as the process source is concerned then we can think of three possible causes related to it and they are insufficient market analysis, larger lead times and poor inventory management. The main cause

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of these three must be insufficient market analysis. It can be because of insufficient data available for study and improper execution of plans. If there is a larger lead time for the whole process, then it can be because of poor internal process handling and due to that delay in order processing takes place. And poor inventory management happens due to imbalance in lead times along with the current policy with which company keep track of their inventory. All and all, technical and procurement team need to work together to solve process related to issues in-order to make the whole process effective in-general.

Communication

The company is using unreliable mediums for communication which is making communication the third problem source. Moreover, lack of man-management skills is also making a huge contribution regarding this and therefore company must use electronic mode of communication if possible, going forward for quotation request and to a certain extent in communicating with other departments as well. In-order to improve man-management skills, the first step is of having proper communication within the company and then with the supplier and for the proper communication medium is necessary.

Technology

There is no option of electronic bid submission and along with that non-use friendly current software is making a lot of trouble for the company people as well and it can be because of use having the lesser knowledge and improper IT training as well. Therefore, company must invest in having a proper supplier portal for the proper communication to happen with suitable medium and a user-friendly software with proper IT training to allow employees of the company to get used it as early as possible.

Management

The fifth problem source is management itself. They use their power in selecting suppliers which should not happen in any case. Moreover, they don't have multiple strategies because of short budget to choose best possible suppliers available in the market for the company. It's material's manager's responsibility to have a proper demand schedule and procurement manager's responsibility to establish proper relations with the suppliers to do business with them for a long time which is not happening currently in an XYZ company.

Supplier

The supplier can also itself be a problem source sometimes when they don't show enough trust along with their lack of capability to deliver service and quality as per their agreement which then forces procurement manager of an XYZ company to take bold decisions.

It is vital to look at all the causes discussed in this phase and then take some measured steps to improve in the improvement phase of DMAIC.

Before that let's take a look at results of Bayesian Network analysis entropy Test with eight cases. Here is how the nodes were connected.

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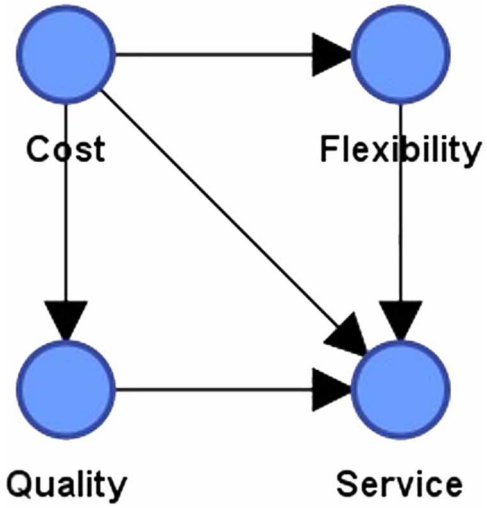
Figure 7. Nodes network connection



Case 1: The Probability of Getting Cost 100% as Per Expectations (Yes)
Case 2: The Probability of Getting Cost 100% as Not Per Expectations (No)
Case 3: The Probability of Getting Quality 100% Proper
Case 4: The Probability of Getting Quality 100% Improper
Case 5: The Probability of Getting Service 100% Yes
Case 6: The Probability of Getting Service 100% No
Case 7: The Probability of Getting Flexibility 100% Yes
Case 8: The Probability of Getting Flexibility 100% No
Case 9: Final Result With 5000 Rows of Data

Now, let's have a look at Target Mean Analysis which can be done using Bayesia Lab Software. Basically, it shows that when the probability of getting cost as per expectation is 66.9688 and not as per expectation is 33.0312 at that time what will be the probability range of having other attributes in either positive and negative manner and it can easily be observed from the below image.

Improve

Let's have a look at improved process map first which further helps the company in following a proper procedure going forward.

After having the improved process map, it's important to do Failure Mode Effects Analysis which aids in defining and describing problems in the current process along with recommendations to improve the current process.

Here, the most impacting failure mode has been shown in the FMEA sheet which says that it is the market analysis and make or buy decision which needs to be done using all proper sources to improve the current supplier selection process of the company and along with that seven other failure modes and in-order to remove or reduce them, recommended actions have also been suggested.

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Figure 8. Case 1

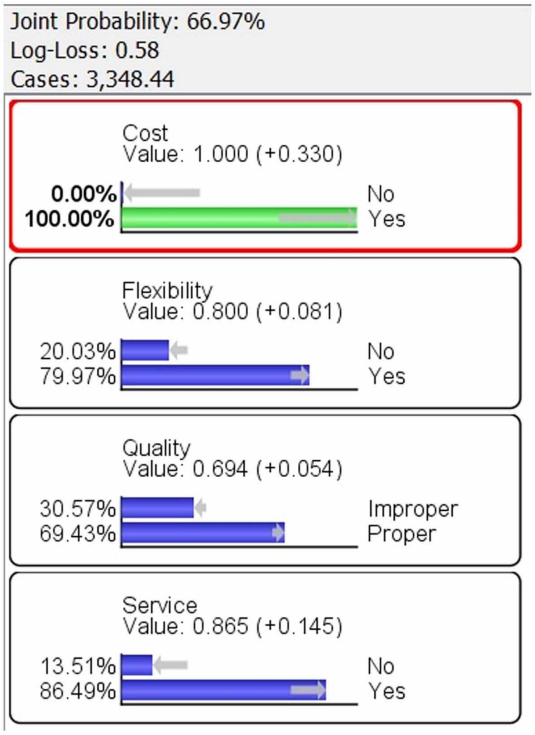

Figure 9. Case 2

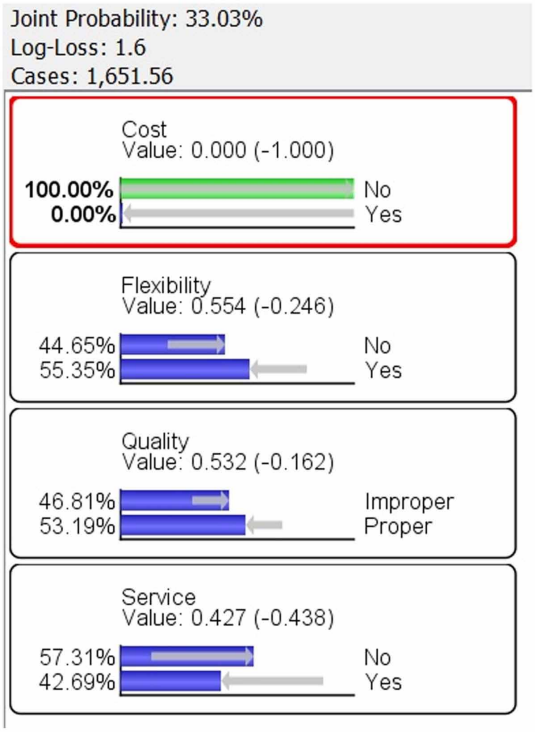

Figure 10. Case 3

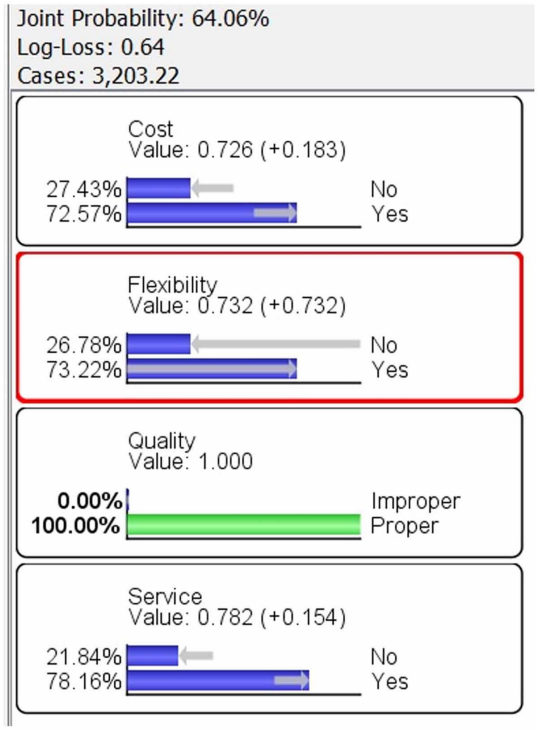

Figure 11. Case 4

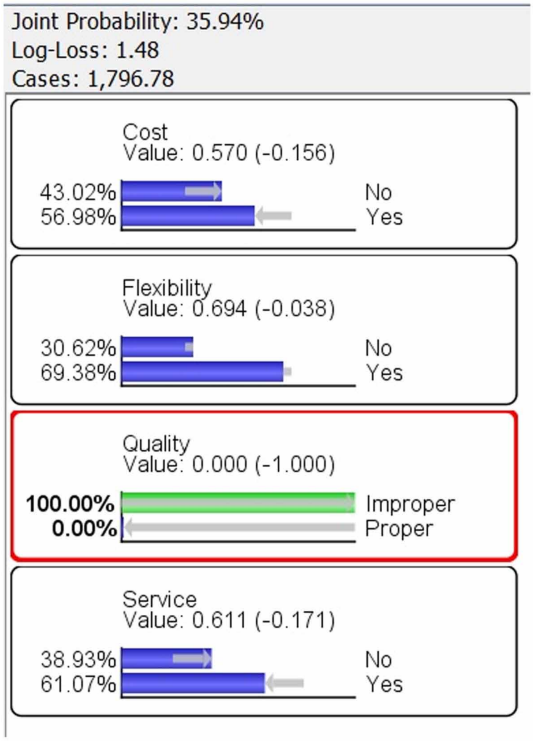

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Figure 12. Case 5

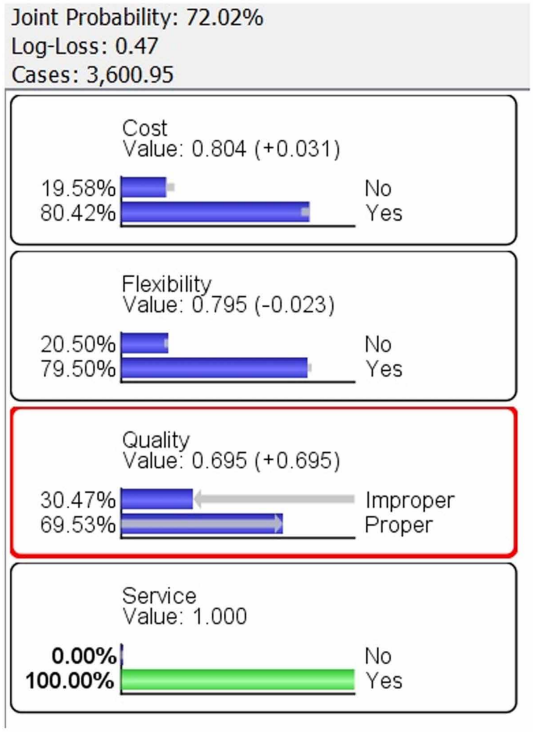

Figure 13. Case 6

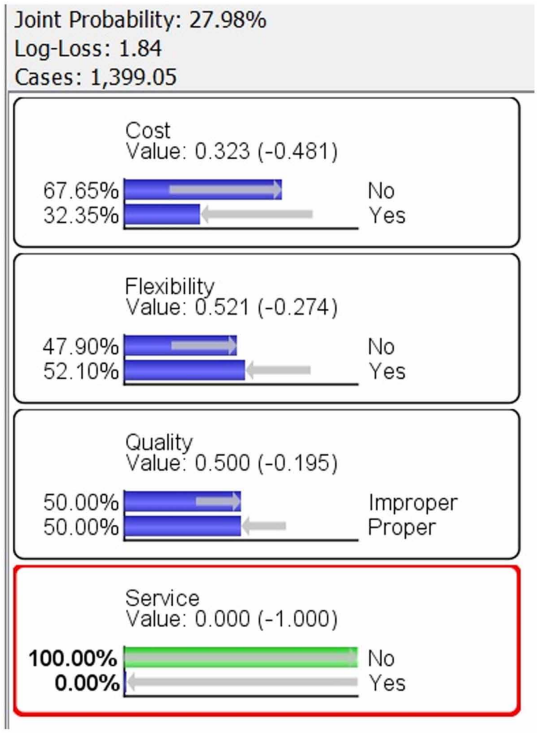

Figure 14. Case 7

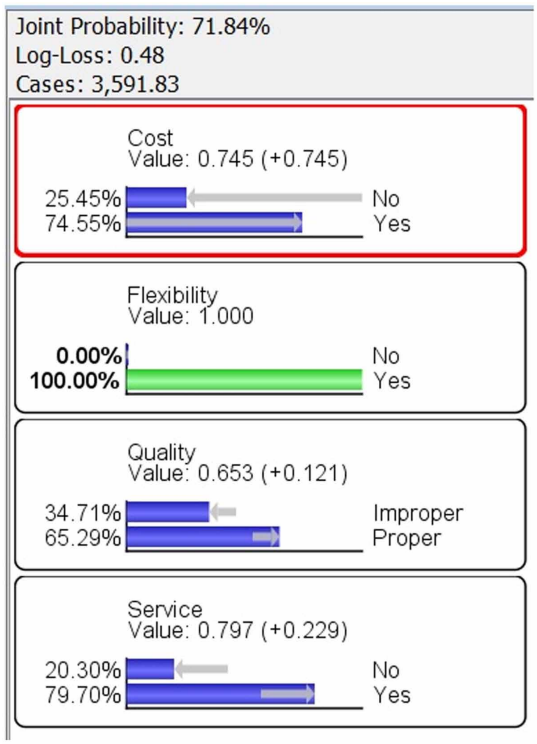

Figure 15. Case 8

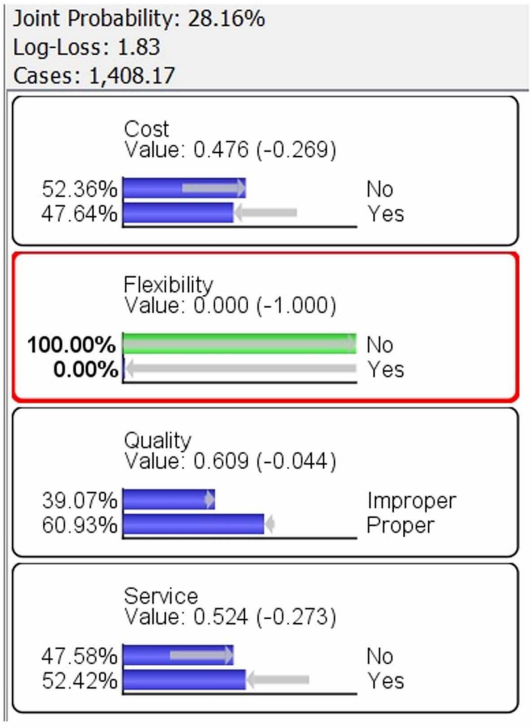

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Figure 16. Final result

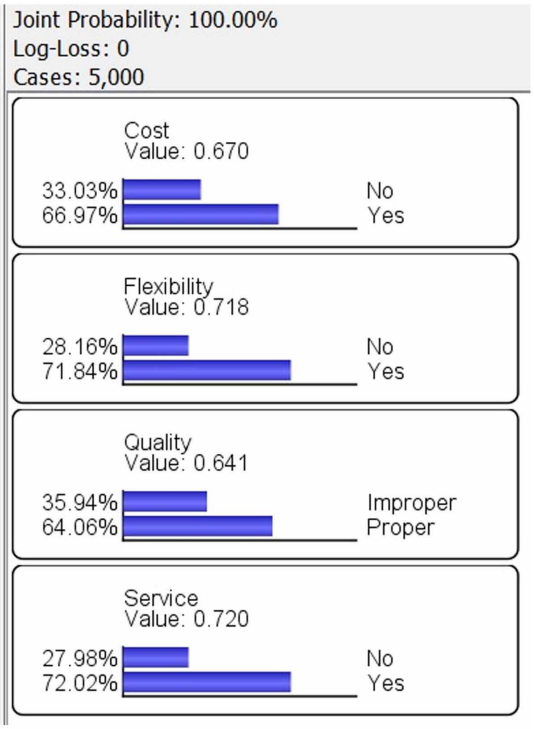
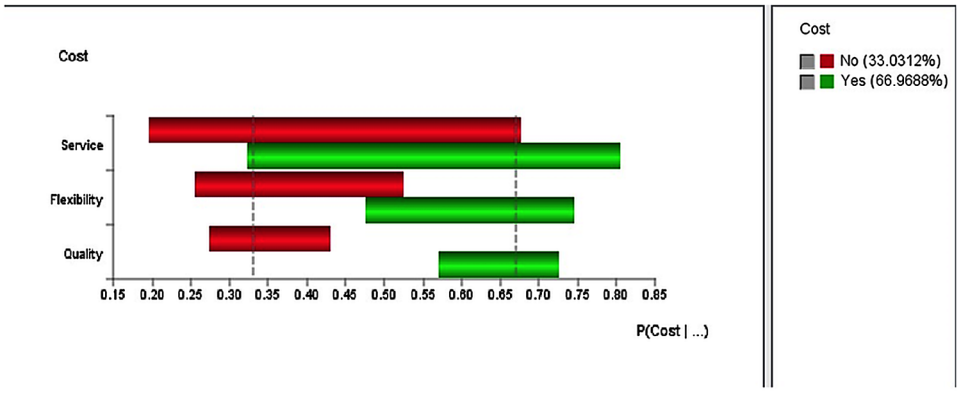


Figure 17. Target mean analysis



Control

This is the last stage of DMAIC methodology and here it's vital to keep an eye on suggested actions for the continuous improvement in the supplier selection process of an XYZ company. For that to happen, it is necessary for the company to gather information from previous three stages to design the whole continuous improvement process and then the time to review it should also be decided accordingly to keep a track of it as whether it has been implemented properly or not.

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Table 18. Failure mode effects analysis

Failure Mode	Effect	Cause	OCC	SEV	DET	RPN	Recommended Actions
PR Identification Need	High Total Cost of Ownership	Improper material requirement planning	7	6	8	336	Proper forecasting and target cost defining
Make or Buy decision and Market Analysis	Buying what can be made in-house	Lack of investment in having in-house experts	8	7	9	**504**	Analyze all sources of market intelligence
Qualification Criteria	Dropping out on decent suppliers with misunderstanding	Lack of co-ordination between technical and procurement team	6	7	6	252	Analyze and review trivial criteria
Mode of Procurement in Bidding	Biasness	Use of power in an unethical manner	5	5	2	50	Give equal chance to everyone
	Manual transaction	Direct purchase	6	6	3	108	Look out for effective mode of trasncation
Evaluation Criteria after QR	Missing out on other key criteria	Lack of management thinking capability	7	7	7	343	Use SOCCER model with H&S and E&S
Supplier Categorisation	Improper database development	Improper process strategy	7	4	4	112	Make a list of category of suppliers
Selection of Supplier	Multiplication of paperwork	Unnecessary activities	5	3	4	60	Remove unnecessary paperwork
Negotiation Strategy	High delay in process	Improper survey and review	6	5	5	150	Proper survey while selecting a supplier and formalize duration of negotiation

The key step for an XYZ company should be to follow the new process map as much as possible and then focus on utilizing all the potential sources available for the market analysis along with forming key multiple strategies for the process along with having proper training of employees, supplier portal generation, elimination of trivial activities and using proper communication medium for communication with suppliers.

Co-ordination among different participating teams alongwith education will also aid an XYZ company to improve current supplier selection process for a long time.

FUTURE RESEARCH DIRECTIONS

Based on the finding of this project, it can be said that the further research can be done using change management concept as it will help in supporting and understanding the change and its effect on the organization. Moreover, sourcing and supplier relationship concept can also be explored to reduce cost and increase reliability.

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CONCLUSION

The conclusion statement in-brief will be presented in the same format as the DMAIC methodology.

Define

In the define phase, CTQ chart along with the purchasing product family was presented to set a path for the supplier selection process.

Measure

In-order to know the current supplier selection process, process map was presented and then Analytical Hierarchy Process was used to know that which factor is the most important among all the selected attributes. Furthermore, the probability combinations were presented for all the attributes to analyze it during the analysis phase.

Analyze

In the analysis phase, 5W2H method along with Cause-and-Effect diagram was used to carry out in-depth analysis regarding the current process in-order to know the loopholes and to accrue them in the following stage. Entropy Test results and Target Mean Analysis results were also presented during this phase.

Improve

In the fourth stage of DMAIC, new improved process map was presented along with Failure Mode Effective Analysis (FMEA) to know how improvements can be made in the current supplier process.

Control

In the last phase, suggestions were recommended to have a continuous improvement process for the supplier selection and to have standardization for the same in an XYZ company.

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KEY TERMS AND DEFINITIONS

Analytical Hierarchy Process: A tool for designing and analyzing complex decisions.

Bayesian Network: A probabilistic graphical model which uses Bayesian inference for the calculation of probability.

CTQ: A key measurable characteristics of a product or a process in-order to fulfill customer requirements.

DMAIC: A problem-solving methodology used in Six Sigma and an acronym for define, measure, analyze, improve, and control.

Failure Mode and Effects Analysis: Used to identify failure modes in a system, its causes and effects.

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Process Mapping: Drawn to understand about the workflow of a process.
Six Sigma: A method used to remove defects in a process using relevant data.

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Chapter 16
Improving Bikesharing Service Quality:
A Case Study for BIXI Montreal

Lakshmi Suvarchla Yalavarthi
Concordia University, Canada

ABSTRACT

Bike sharing is a typically structured non-motorized transportation service that provides users point-to-point transportation. The services are flexible to users as they do not have to wait in a line to pick up a bicycle from any bike sharing system and can return it to any other location of the bike sharing system. This chapter mainly focuses on why it is important to use bike sharing transportation rather than any other mode of transportation. In this chapter, the authors address the customer satisfaction level and focus on the service quality of the bike sharing system BIXI in Montreal. A questionnaire survey is conducted with the users of BIXI. A total of 580 responses are collected. Descriptive statistics, complaint analysis, and data analysis are done to identify areas of improvement.

INTRODUCTION

Public transportation is always a vital part of the economy since it also has to implement environmental protection plans for energy conservation and to achieve the long term objective of sustainable development. With the increasing population in any country, the need for transportation also increases and considering the facts to create an eco-friendly mode of transportation is critical and never-ending. Over the past years, there have been several studies on environmental protection plans and how transportation being one of them to support the environment in any possible by reducing the pollution caused by it. Bicycle-friendly towns are a common concept proposed by many countries but are only followed by some of the countries. Moreover, almost 50 countries in five continents have the public bike share systems by June 2014 (Thompson, n.d.).

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Bike sharing is a typically structured non-motorized transportation service that provides users point-to-point transportation. The services are flexible to users as they do not have to wait in a line to pick up a bicycle from any bike sharing system and can return it any other location of the bike sharing system. Generally, the bike sharing system is structured in a way that has a customer kiosk and a dock station that has bicycles. Every dock station has a limited number of bicycles that it can hold. A docking station is a place where a bicycle can be parked and locked until the popup sound can be heard by the user. The customer kiosk is an electronic terminal where the user can read all the rental instructions, payment options, and other options. Usage fees or membership details are provided on the online portal and the additional charges costs are also given.

Montreal is one of the cold cities in Canada that started the concept of bike sharing. Bike Sharing was introduced by Public Bike System Company (PBSC) in May 2009 (Wikipedia, 2019b). Even though it was not a big success in the starting period eventually it picked up later and is one of the large-scale companies in North America. When it was started, there were a lot of thefts and the service quality provided by PBSC was not good.

Bike sharing systems are mainly carried out by two organizations: Local community or non-profit organizations and Government organizations. The main idea of these systems is providing bikes at affordable prices and free access on special occasions to reduce traffic congestion in the city and contributing to keeping the cities green and healthy.

Some reasons for using bike sharing systems by people are theft, vandalism, parking issues, maintenance requirements and ease of access. For some countries, with the advancement of technology, the issue missing out is reducing pollution and having such bike sharing systems not only help in reducing the pollution but at the same time, it is less crowded in other modes of transportation as well.

BIXI originally came from combing bicycle and taxi. It was founded by Michel Gourneau following a contest asking Montrealers to help identify the bike. By the end of the year 2013, PBSC faced a huge loss and went bankrupt after which it was undertaken by the city of Montreal in the year 2014, therefore the name changed to BIXI Montreal. It is a non-profit organization.

The BIXI network has 540 stations and 6250 bikes across the city of Montreal, Longueuil and Westmount (These numbers are taken from links provided in the references). Furthermore, there has been a success rate in the past year 2017 compared to previous years. It runs 24/7 making is available at any time of the day. It runs from April 15 through November 15 and has different promotional offers every time of each year. BIXI online website can also be accessed by anyone to get more information. They also have a BIXI app which is compatible with all the smartphones mostly. BIXI offers monthly payments, one day access and mostly the docking station systems are available in different languages.

This paper is mainly focused on customer satisfaction and quality standards including the reasons why is better than other modes of transportation. This paper consists of a literature review of BIXI, Montreal and then is with a different bike sharing system in Brisbane, Australia. Secondly, Conclusion and future works are discussed.

EVALUATION OF SERVICE QUALITY

The quality evaluation of products and services is an important parameter for any company for the betterment of their products or services and aiming for customer satisfaction. The quality of goods is measurable objectively with the help of a total number of defective goods and their durability. But the

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quality of service will require some tools to measure which also includes the history of the service. Therefore, there are different definitions of service quality proposed by the researchers, but customer satisfaction was one of the most important among them (e.g. LeBlanc & Nguyen. 1997, Nagata et al, 2004; Edvarsson, 1988).

BIXI service quality represents an evaluation of bike/riders on the overall performance of BIXI service. The performance of BIXI service increases with an increase in customers every year and by satisfying their needs. In general, some of the techniques used for evaluating the service quality are In-App Survey and Post service rating.

In-App Survey

In-app survey is one of the best methods to get the complete information about the service, the process followed was every customer who is registered online in the service or the person who is surveying the app currently will be asked questions regarding the app and service like how useful did they find the website, was there any information missing from company's sights, or it will be about what are the developments you want the company to do in the application so that you people could understand it more easily while registering and using that . In this process, the company can get advantages and disadvantages regarding their service.

Post Service Rating

This is a method of asking customers right after their service which includes a special chat box developed for them where they can chat with several customer representatives about the service and can even rate it out of 5. On the other hand, there is another option where customer representatives will contact you through phone and you can elaborate on all your issues faced while using the service and scaling the app based on the way how customers react to it.

A Survey was conducted to evaluate the service quality and based on which the customer expectations were known, and some expectations were met.

SURVEY

The survey for this paper was done through social media sites and additionally in person were handed out to the customers. The survey had a total of 21 questions including suggestions from the customers in the end. A total of 580 responses were collected in the end and some feedbacks were provided by the customers. These responses include 300 in-person surveys and 280 online responses. The questionnaire is provided in the appendix.

The survey responses were analyzed using complaint analysis. Further, the complaints were used to improve service quality experience. A literature review was used to design the questions for the survey.

Montreal is the second largest city of Canada with an estimated population of 1.7 million (world Population Review, 2019). Montreal has one of the best metro services, but they always get crowded and introducing such bike sharing systems will not only help in reducing the crowd but also contribute towards environmental plans. Montreal is one of the most visited places in Canada for the summer and

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the tourists are attracted to use such bike sharing systems to go around the city and they don't have to think about parking issues or theft (Wikipedia, 2019a).

Since the survey was online, everyone was able to take it without any interruptions and the survey's estimated time taken was 5-6 minutes. This year, 2018, was a huge success for BIXI when it was compared to last year and is making a lot of progress.

SURVEY RESULTS ANALYSIS

Out of the 580 respondents, there were 340 male respondents and 239 female respondents who provided their feedback for this service and by leaving comments as their suggestions to the survey. Some commonly asked questions are given below with the following:

Figure 1.

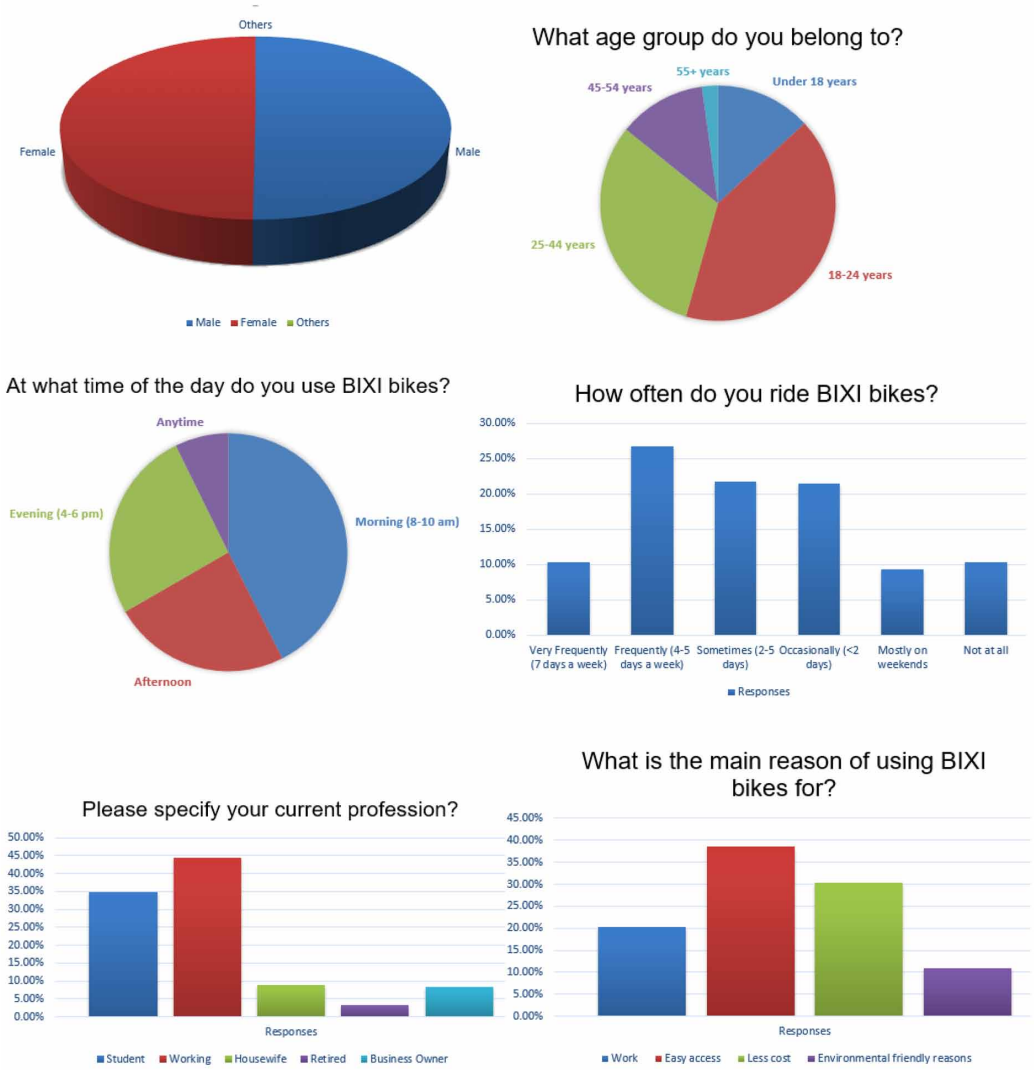

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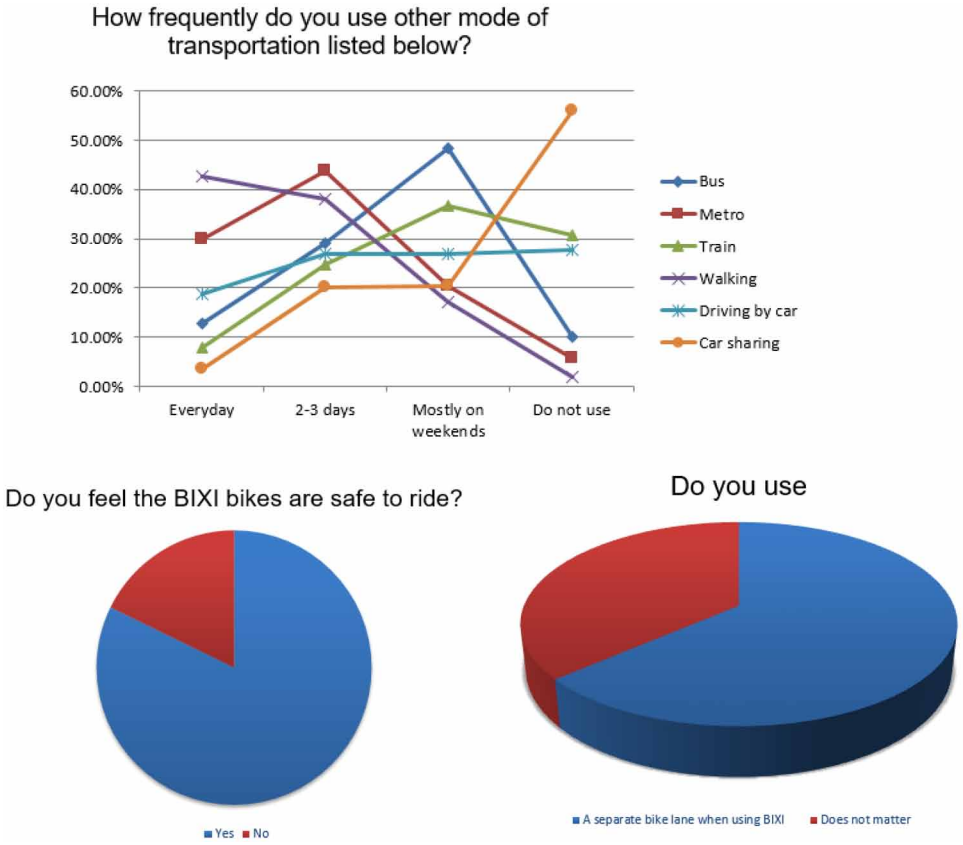
Figure 2.



The reason for using BIXI mostly is that it is easily available and also the membership are affordable including each day access charges too.

The question below was asked to avoid asking too many questions that conclude the same result in the end. All transportation listed below has access throughout the year but BIXI bikes have a duration since they are closed for the whole winter. Futhermore some people suggested that BIXI bikes help maintain their health and are also environment-friendly.

Questions like how safe they feel while riding BIXI, most of the responses were positive and most of the customers were not bothered by having a separate lane but said if they have it then it would be an additional benefit towards the safety of the customers. Though most of the places in Montreal, has separate lanes mostly the areas where it is always crowded but having lanes in other streets too would be beneficial.

Although wearing helmets is not mandatory in Montreal, most of them still wear them for their safety and when they go for long rides on the bikes. When a question was framed on this majority of them wear helmets for their security since they claim that some lanes do not have separate bike lanes.

While asking the flowing question below since it had a lot of choices the weighted average was calculated to use in the resulted graph shown below:

So mostly the main reason for using BIXI for people living farther away from downtown was to connect to metro stations since they were a bit away from their houses.

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Figure 3.

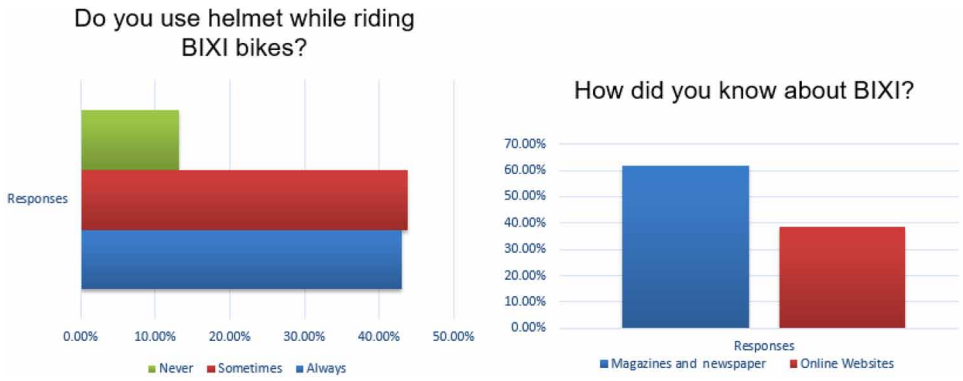
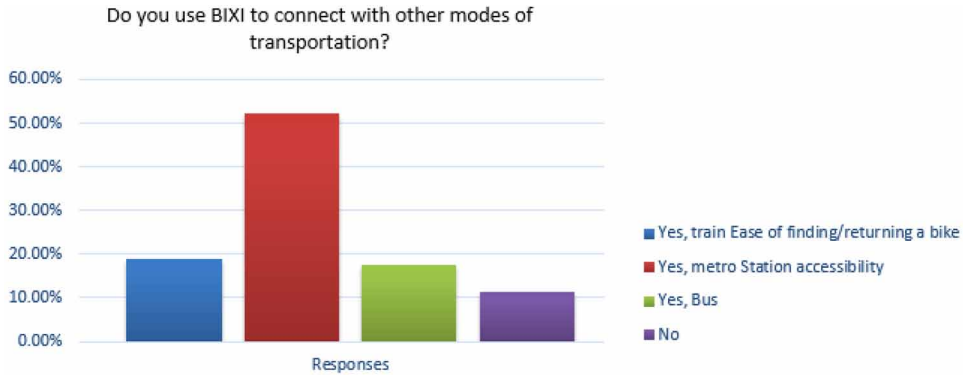


Figure 4.



While rating in terms of the difficulty of using BIXI the weighted averages were calculated and hence the graph was obtained.

Users concerns were mainly related to having more docking stations in certain areas that stated in the appendix at the end of the report. The maintenance of the bikes is done on time as said when the survey was done in person with some regular users of BIXI. According to the survey, this year 2018 the BIXI also introduced electric bikes in some locations which were far more amazing than the regular ones resulting in huge success for them.

Some users even said that the services provided by the BIXI such as the maintenance and moving the bike from one location where the dock stations are full to another location where the dock stations are empty was handled well. In addition to that, if GPS systems are added on the bikes then it would the outlook of the bikes while providing the users to locations easily.

DATA ANALYSIS

First, we look at BIXI data. The website provides us open source data which helps us to track the trip information, sales and membership usage data. As you can see below: (https://www.bixi.com/en/open-data)

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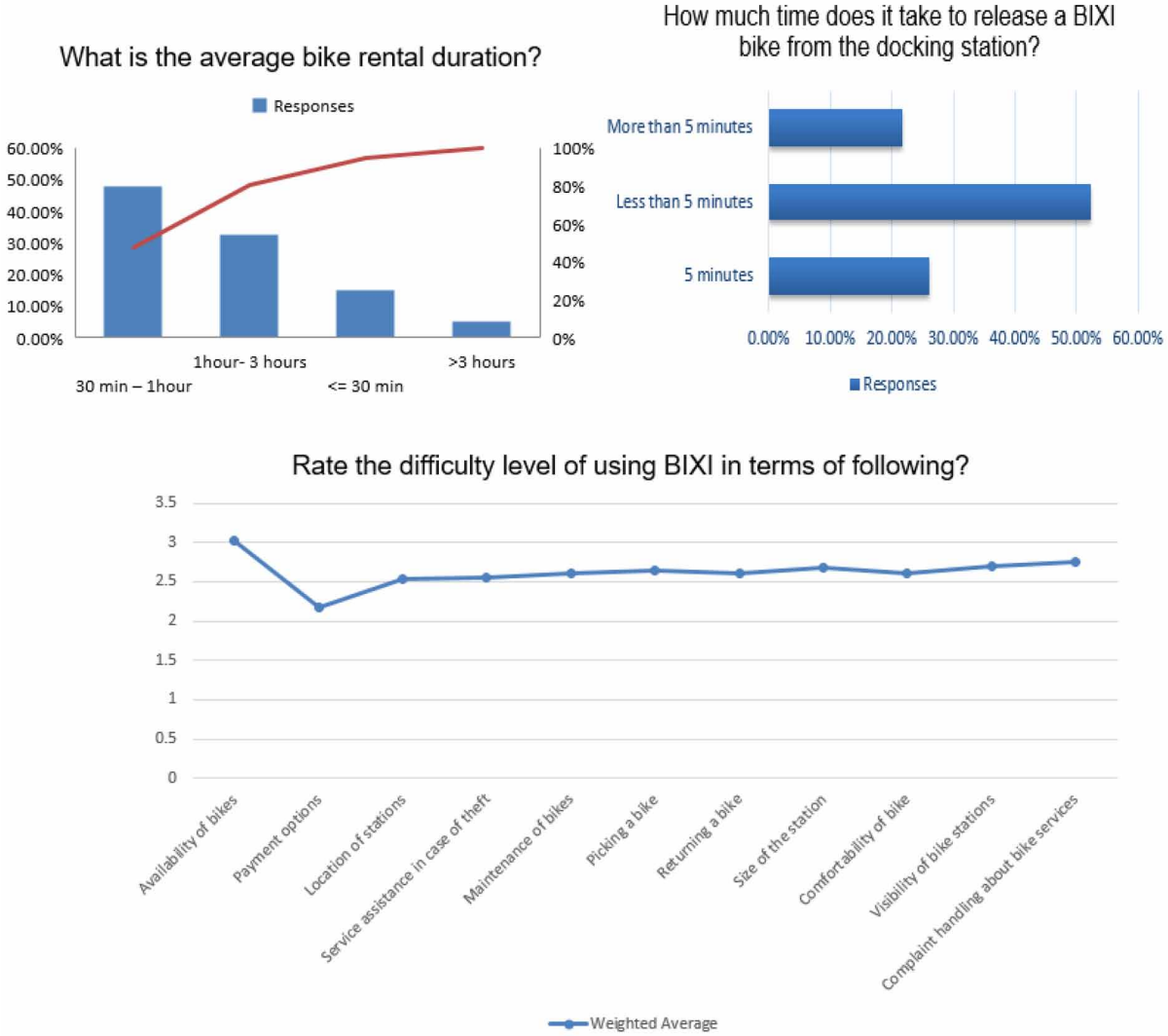
Figure 5.



The above graph represents the number of purchases of memberships and short-term access vs number of users. This graph was for the year 2018.

The website also provides a GPFS feed also known as real-time data which gives us system information (https://api-core.bixi.com/gbfs/en/system_information.json), station status (https://api-core.bixi.com/gbfs/en/station_status.json), system alerts (https://api-core.bixi.com/gbfs/en/system_alerts.json), and station information (https://api-core.bixi.com/gbfs/en/station_information.json).

When passing the survey to the customers I also notified them about the data analysis part and asked them how they feel about it.

Some customers gave feedback about this which are listed below.

I am an immigrant here so having such bikes in summer is actually amazing since its lot faster to travel and less costly.

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Figure 6.

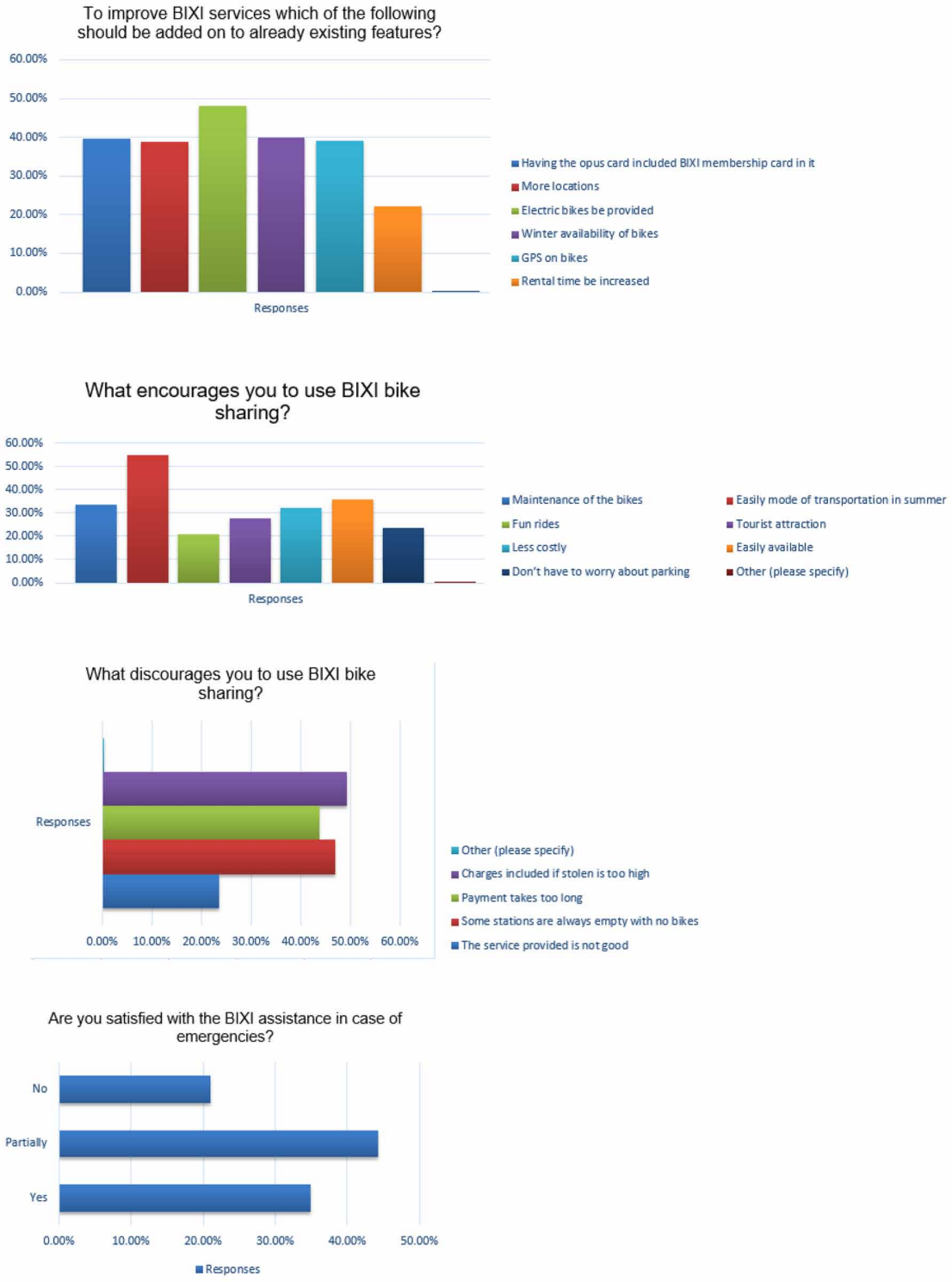

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Figure 7.

BIXI bikes are great and they also have new electric bikes this year and they are great. I mainly use the bikes to work.

The information provided on the website is way easier compared to my country where such services are not operated properly.

There is lot of improvement throughout the years in BIXI since I have been using them for a long time.

The memberships are lot less if we have our metro cards with us which helps me a lot since I live from the metro station and this is service is easily accessible for me.

Finding a docking station is easy as they have a BIXI mobile app.

Sometimes the customer service is very poor which makes me think of not choosing this service very often.

I would like to have a docking station near my place since I have to walk a longer distance sometimes to find a docking station.

I am an international student and choosing this service helps me a lot since I can reach my work place faster than usual and back in my country there are no such services provided.

OTHER BIKE SHARING SYSTEMS

Bike Sharing in Brisbane, Australia

The bike sharing system in Brisbane, Australia is also frequently known as a City Cycle bike sharing. The main problem with this system is they only have online signups. The website for bike sharing is

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not clear to a new user using the website. Some actions like wearing helmets are mandatory whereas it should be the choice of the user. Furthermore, they are some factors affecting the bike share membership such as the income of the individuals.

As this part of Australia has normal temperatures throughout the year and also with the increasing population in the country the bike sharing is one best solution they came up with. They also had focus groups to study the barriers and factors affecting the public bicycle schemes. The users also had issues with the docking stations. The stations were not located in the most accessible areas and the users to walk far distances just to retrieve the bicycles. The payment mode online only and the members were charged every month. Being a member, the users using the service should have the access to not pay the month they don't use and should be able to recharge the cards the month they want to use it.

There were surveys conducted by asking most of the already existing users, non-users of bike sharing and some other communities. (Source - https://www.sciencedirect.com/science/article/pii/S1369847812000733)

Also biking sharing websites mostly do not provide trip information, and other open data sources. This causes a greater influence for the customers if they want to see the statistics of the previous year. But BIXI, Montreal website provides open sources to anyone accessing the website. (https://www.bixi.com/en/open-data)

The case study was done to analyze the limitations associated with the bike sharing system. This bike sharing systems regulations are far more complicated if compared to BIXI bikes. The BIXI has been increasing in demand and is being more popular every year but whereas Brisbane's bike sharing is not as compatible as BIXI. Serval case studies and many other tools were used to address the barriers faced by the City Cycle, Brisbane.

CONCLUSION AND FUTURE WORKS

This paper has analyzed the survey results has presented the approaches in evaluating bike sharing using the service quality techniques. According to the outcomes of the results there, some suggestions were given by the users that have been using this bike sharing for years. Introducing new features to the existing BIXI bikes will result in more users. Also, other suggestions were provided during the survey that can be accounted for the quality improvement of this service are:

- Install GPS for the bikes
- Introduce electric bikes in more locations
- Spread the BIXI concept across Canada
- Install air pumps in the docking stations
- Increase the rental time to 1 hour
- Install mobile holders
- Increase maintenance facilities for the bikes
- Provide maps at every docking station

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APPENDIX

BIXI Bike Sharing, Montreal Questionnaire

1) Select that applies to you
   a) Male
   b) Female
   c) Others
2) How often do you ride BIXI bikes?
   a) Very frequently (7 days a week)
   b) Frequently (4-5 days a week)
   c) Sometimes (2-5 days)
   d) Occasionally (<2 days)
   e) Mostly on weekends
   f) Not at all
3) What age group do you belong to?
   a) Under 18 years
   b) 18-24 years
   c) 25-44 years
   d) 45-54 years
   e) 55+ years
4) At what time of the day do you use BIXI bikes?
   a) Morning (8-10 am)
   b) Afternoon
   c) Evening (4-6 pm)
   d) Anytime
5) Please specify your current profession?
   a) Student
   b) Working
   c) Housewife
   d) Retired
   e) Business owner
6) What is the main of using BIXI bikes?
   a) Work
   b) Easy access
   c) Less cost
   d) Environment-friendly reasons
7) How frequently do you use other modes of transportation listed in the below table?

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Table 1.

	Everyday	2-3 days	Mostly on weekends	Do not use
Bus				
Metro				
Walking				
Driving by car				
Car sharing				

8) Do you feel the BIXI bikes are safe to ride?
   a) Yes
   b) No
9) Do you use
   a) A separate bike lane when using BIXI
   b) Does not matter
10) Do you use a helmet while riding BIXI bikes?
   a) Always
   b) Sometimes
   c) Never
11) How did you know about BIXI?
   a) Magazines and newspaper
   b) Online websites
   c) Through friends
   d) Others
12) Do you use BIXI to connect with other modes of transportation?
   a) Yes, train (ease of finding/returning the bike)
   b) Yes, metro accessibility
   c) Yes, bus
   d) No
13) What is the average bike rental duration?
   a) <= 30 minutes
   b) 30 min-1hour
   c) 1hour- 3hours
   d) >3 hours
14) Rate the difficulty level of BIXI in terms of the following?

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Table 2.

	Very Easy	Easy	Neither	Difficult	Very Difficult
Availability of Bikes					
Payment Options					
Location of Stations					
Picking A Bike					
Returning A Bike					
Size of The Station					
Visibility of Stations					
Service Assistance in case of theft					
Comfortability of The Bike					
Maintenance of Bikes					
Complaint Handling of Bikes					

15) How much time does it take to release a BIXI bike from the docking station?
    a) 5 minutes
    b) Less than 5 minutes
    c) More than 5 minutes
16) To improve BIXI services which of the following should be added on?
    a) Having the opus card included with BIXI membership card in it
    b) More locations
    c) Electric bikes should be introduced
    d) Winter availability of bikes
    e) GPS on bikes
    f) Rental time should be increased
    g) Others (please specify)
17) Do you need more BIXI stations in specific locations? If yes, please specify the location?
18) What encourages you to use BIXI bike sharing? (Tick all that apply)
    a) Maintenance of the bikes
    b) Easily mode of transportation in the summer
    c) Great scenery
    d) Tourist attraction
    e) Fun Rides
    f) Less costly
    g) Easily available
    h) Don't have to worry about parking
    i) Others (specify)
19) What discourages you to use BIXI bike sharing? (Tick all that apply)
    a) The service provided is not good
    b) Some stations are always empty with no bikes
    c) Payment takes too long

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d) Charges included if stolen is too high
e) Others (Specify)

20) Are you satisfied with the BIXI assistance in case of emergencies?
Yes
Partially
No (please specify)

21) Do you have any other suggestions to improve BIXI services?

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Chapter 17
Risk Management in Supplier Selection:
A FMEA-Based Approach for Retail Supply Chain

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ABSTRACT

Risk management issues have been widely researched in areas such as system engineering, business management, financial planning, market research, and service industry. Many approaches have been proposed to reduce or minimize risks, maintain productivity or profitability in organizations. However, different risk management strategies are needed under different situations and different industries. In this chapter, the authors address the theme of risk management in supply chains. They begin by reviewing the metrics of supply chain performance, followed by design and development of supplier relationship management process, and a failure modes and effects analysis (FMEA)-based approach to identify and evaluate the potential risks in the process of commodity procurement. After analyzing the causes and effects of potential risks in procurement, they develop a strategic plan to monitor and control risk management and implement continuous improvement. A case study is provided for supplier selection and buyer-supplier relationship management.

INTRODUCTION

In the past several years, the topic of supply chain risk management has been researched and discussed in the inner circles of operations professionals, business management references and so on. However, until recently, very little has been done to help organizations to evaluate and measure their degree of exposed supplier risks and more importantly, how to manage these risks exposed to the facilities throughout the supply chain.

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As a definition of SCOR risk management mode, "Supply chain risk management is the systematic identification, assessment, and quantification of potential supply chain disruptions with the objective to control exposure to risk or reduce its negative impact on supply chain performance (SCOR, 2007)." In SCOR 8.0 mode, we might see that "Potential disruptions can either occur within the supply chain (e.g. insufficient quality, unreliable suppliers, machine break-down, uncertain demand etc.) or outside the supply chain (e.g. flooding, terrorism, labor strikes, natural disasters, large variability in demand etc.)." And also, "Management of risk includes the development of continuous strategies designed to control, mitigate, reduce, or eliminate risk." Therefore, with the SCOR risk management model, the contents include identifying risk, designing detection measures, controlling risks exposure, and eliminating risks.

In the literature of Wagner and Bode (2006), it is easy to distinguish such terms:

- *Risks in Supply chain*: The risk is defined as a negative deviation from the expectation of valuing a certain performance measure, resulting in negative consequences for the focal firm or a certain supply chain facility. Hence, risks are equated with the detriments of a supply chain disruption. The authors explicitly adopt the notion of risk as purely negative as the one that corresponds best to supply chain business reality. As a consequence, they do not consider "happy disasters" nor the situation where managers intentionally "gamble" on risk.
- *Disruption in Supply chain*: a supply chain disruption is an unintended, untoward situation leading to supply chain risk. For the affected firms or supply chain facilities, it is an exceptional and anomalous situation in comparison to every-day business. Supply chain disruptions can materialize from various internal and external areas into a supply chain. Consequently, their nature can be highly divergent.
- *Risk source in Supply chain*: attempting to circumscribe supply chain disruptions (i.e. the demarcation of supply chain risks from another business risk), many scholars have proposed classifications in the form of typologies and/or taxonomies of risks. The derived classes of supply chain disruptions are often labeled supply chain risk sources.
- *Supply chain vulnerability:* while a supply chain disruption is a situation that leads to the occurrence of risk, it is not the sole determinant of the final result. It seems consequential that also the susceptibility of the supply chain to the harm of this situation is of significant relevance. This leads to the concept of supply chain vulnerability. In another way, Christopher and Peck (2004) define supply chain vulnerability as "an exposure to serious disturbance", while Barnes and Oloruntoba (2005) describe vulnerability as "a susceptibility or predisposition to loss because of existing organizational or functional practices or conditions".

Hence, to sum up, supply chain risk management can be described as the management of the supply chain risks through coordination or collaboration among the supply chain partners, so as to avoid business failures and ensure profitability and continuity. Then, the aim of risk management would be to plan a management strategy to detect risks, control failures, monitor the process of implementing risk management, audit and evaluate the results. All the countermeasures are serving to safeguard continuity and maximize profitability (Tang, 2005). Additionally, the mechanism of procurement risk management is often created through an agreement between buyers and suppliers with the purpose of these efforts being to avoid the damage caused by buyer uncertainty, system malfunction, buyer or supplier error, and product or service mismatch (Tang & Shee et al., 2001).

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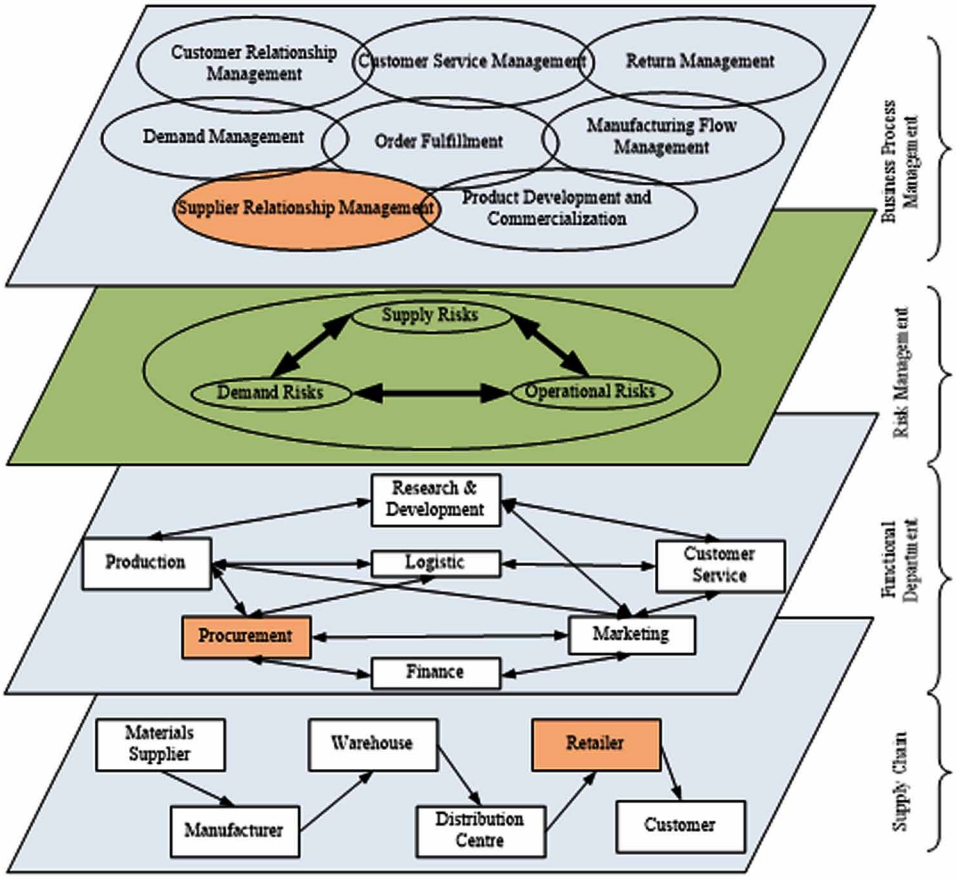
Figure 1. The relationship of risks with components of supply chain



In Figure 1, it is shown that there is a logical diagram to elaborate the relationship among supply chain activities, functional departments of a specific organization, business processes and risk management. Between functional department blueprint and business process frame, risk management can be understood as a combination of those two layers. It means that risk management can be integrated into all business processes, and also it may implicit that there is some specific work among different departments in an organization in order to reduce potential risks or errors. For example, risks should be studied and a management plan executed in Manufacturing Flow Management process. On the other side, for instance, the logistics or transportation work department might mainly focus on how to reduce the risk of transportation cost, logistic collaboration and so on. Thereof, in proceeding this paper, we will largely study risk management of Supplier Relationship Management in the Procurement process, especially for supplier selection.

As shown in the layer of risk management, there are three aspects of risks in the supply chain that include supply risks, demand risks, and operational risk as well. Seeing the first layer at the bottom, these three risk categories might be found in all facilities through the supply chain. In the second layer which is a functional department in an organization, risks will be presented in the real work of all functional activities. Accordingly, any of business process on the top layer contains a large number of risks. In the

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process of Supplier Relationship Management, procurement department of retailer should also have to mainly focus on reducing these three kinds of risks: supply risks, demand risks, and operational risks.

Supply Risks categorize those risks that are existing uncertainty within a buyer-supplier relationship, damage of its performance and errors in product or service supply process. Thus, many supply risks are listed as followings:

- High variability of supplying product or service quality
- Lack of flexibility of purchasing contract
- Lack of enough productivity of product or service
- Lack of quick responsiveness from suppliers
- Lack of technical or financial support

Likewise, Demand Risks include the issues related to customer demand and order processing.

- High variability of order demand
- Low accuracy of demand forecast
- Low order fulfillment
- Low fill rate
- Long lead time

Furthermore, Operational Risks contain management factors and cooperation problems including but not limited to the following issue:

- Lack of the standard, mature work processes
- Inefficient communication and cooperation
- Lack of the flexibility of pricing strategy
- Lack of a quality assurance system and audit mechanism
- Lack of continuous improvement
- Lack of the effective negotiation mechanism
- Low level of information sharing and data exchanging
- Lack of safety protection, a sustainable environment development mechanism

The risks in the mentioned three categories are not indicated as risks only toward buyers or suppliers. Some are risks for both. Having these risks present in the procurement process, buyer and supplier should have to cooperate together so as to detect, evaluate and reduce them. However, although it is important to qualify the risks in the process of dealing buyer-supplier relationship, it is difficult to quantify the risk degree. Thereof, this paper will establish a risk detection approach, and develop the metrics to evaluate the level of different risks in order to quantify the risks in the procurement process. After that, through a case study, we will design a continuous improvement plan so that FMEA approach can be applied to reduce potential risks for dealing buyer-supplier relationship.

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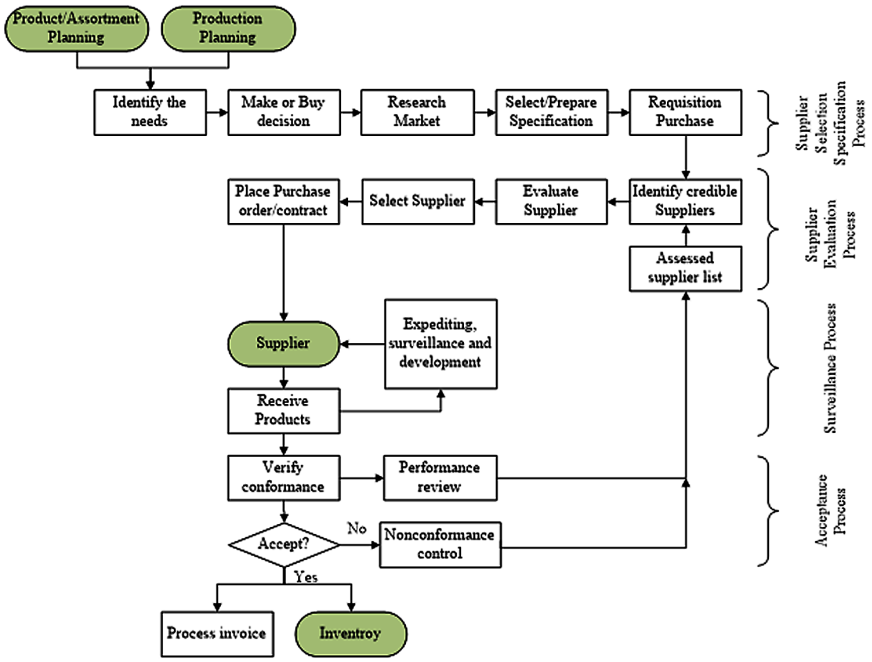
BACKGROUND

In this paper, we will demonstrate what risk management in supply chain is, types of potential risks in procurement, how to detect and quantify them in the process of supplier selection, and what are the recommended avenues to reduce risks so as to improve the reliability of purchasing commodity. After interpreting risk management and determining potential risks in procurement, we will provide additional details about the procurement process, supplier relationship management, and FMEA methodology. FMEA is a risk analysis tool that can be used in the design process to improve the reliability of a product (Anleitner 2010; Carlson 2012). The reasons why this method has been chosen between all other similar risk management solutions, will also be discussed in detail in this section.

First, as procurement defines, the objective is to purchase the right quality of material, in the right quantity, at the right time, from the right source or right supplier, at the right price (Fernandez, 1995). Therefore, there are many tasks to focus on in the procurement process, indcluding the following:

- To supply the organization with a steady flow of materials and services to meet its needs;
- To ensure continuity of supply by maintaining an effective relationship with existing sources and by developing other sources of supply either as alternatives or to meet emerging or planned needs;
- To buy efficiently and wisely, obtaining by any ethical means the best value for every pound spent;
- To manage inventory so as to deliver the best possible service to users at the lowest cost;
- To maintain sound co-operative relationships with other departments, providing information and advice as necessary to ensure the effective operation of the organization as a whole;
- To develop staff, policies, procedures, and organization to ensure the achievement of the foregoing objectives.

Figure 2. Procurement process map (derived from Hoyle, 2006)



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From Figure 2, we could see a detailed procurement process map. To detect risks in this process, although each step may contain potential risks, the main task of this paper is working on supplier relationship management, especially in supplier Selection which is mainly composited by "Supplier Selection Specification Process" and "Supplier Evaluation Process".

Second, supplier relationship management has been deeply researched for decades. For early years, Farmer (1985) elaborated its contents in retail industry. The buyer-supplier relationship management principally deals with:

1. **The Product**: New or scarce product planning and buying; Existing product eliminating.
2. **The Price:** Key point of negotiation since the gross margin, the percentage of profit between buying and selling prices are one of the principal accountabilities.
3. **Payment Terms:** Cash flow may be difficult, or there may be a 'false' position for a company's year-end balance sheet.
4. **Delivery and Distribution:** Knowledge of the costs of warehousing and of distribution is becoming better understood by buyers. Company policy may dictate the desirability of delivery to individual shops or to regional/central warehouses or redistribution centers. It is important for the buyer to have detailed knowledge of these costs in order that he can calculate whether the mix of buying prices, payment terms and delivery terms is the optimum in a particular circumstance.
5. **Advertising Promotion:** The majority of retailers, however, acquire funds to cover their A&P (Advertising and promotion) from their suppliers. Many suppliers have come to expect this, and in all probability try to cost it into the buying price. Others, however, see the product, price A&P etc., as having quite separate budgets, and the skilled buyer will seek to obtain maximum revenue from each source. Nevertheless, as with all forms of buying it is necessary to consider the whole mix – product, price, payment etc.

With the development of the market and economy, new issues emerged during the past decades. Although those principal elements that Farmer's supplier relationship management theory embraced are still the main composites of the purchasing process.

The immediate objective of Supplier Relationship Management (SRM) is to streamline and make the sourcing processes more effective between an enterprise and its suppliers. Indirectly, SRM is also aiming at quality-related improvements in information, products, services, and workforce capabilities. A commonly agreed definition of what SRM exactly comprises does not exist to date. Consecutively, some sample definitions – from academia and practice – are given below:

- "Supplier relationship management is the process that defines how a company interacts with its suppliers. As the name suggests, this is a mirror image of Customer Relationship Management (CRM). Just as a company needs to develop relationships with its customers, it also needs to foster relationships with its suppliers … The desired outcome is a win-win relationship where both parties benefit." (SAP. 2003)
- "SRM is understood as the sourcing policy-based design of strategic and operational procurement processes as well as the configuration of the supplier management." (Appelfeller et al., 2005) "Purchasing and Supply Management is defined as a strategic, enterprise-wide, long-term, multifunctional, dynamic approach to selecting suppliers of goods and services and managing them and the whole value network from raw materials to final customer use and disposal to continually

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reduce total ownership costs, manage risks, and improve performance (quality, responsiveness, reliability, and flexibility)." (Leftwich et al., 2004)

- "SRM includes both business practices and software and is part of the information flow component of supply chain management (SCM). SRM practices create a common frame of reference to enable effective communication between an enterprise and suppliers who may use quite different business practices and terminology. As a result, SRM increases the efficiency of processes associated with acquiring goods and services, managing inventory, and processing materials." (SAP. 2003)
- "SRM … refers to any supplier-facing business practices which are enabled by collaborative software and which allow companies to work with their supplier base for mutual success. Primarily, SRM tools have been developed to reduce the total cost of ownership (TCO) for procured goods, while creating a competitive advantage for an organization through deeper relationships with its suppliers." (Fleming, 2004)

To refine these views, supplier relationship management is set to deal with the physical product flow, margin flow and information flow from supplier to buyer and customer in order to minimize the risks and maximize profitability for both suppliers and buyers. During the process, risks should be investigated, evaluated, controlled and improved.

Third, in this section, we will describe the Failure Modes and Effects (FMEA) approach. As one of the advanced Six Sigma tools (Shina, 2002), FMEA has been applied on manufacturing or service industry to detect the potential risks in processes, and determine the relevant actions to implement continuous improvement. This tool is widely used to establish a reliability engineering activity that also supports fault-tolerant design, testability, safety, logistic support, and related functions. For years, failure modes and effects analysis has been an integral part of engineering designs. For the most part, it has been an indispensable tool for industries such as the aerospace and automobile industries (AIAG, 1993). Government agencies (i.e., USA Air Force and Navy) require that FMEAs be performed on their systems to ensure safety as well as reliability. Most notably, the automotive industry has adopted FMEAs in the design and manufacturing/assembly of automobiles. However, it also can be wonderfully executed in the service area (Day et al., 2007). Although there are many types of FMEAs (design, process, equipment) and analyses vary from hardware to software, one common factor has remained through the years—to resolve potential risk problems before they occur. By taking a functional approach, this guide will allow the designer to perform system design analysis without the traditional component-level material (i.e., parts lists, schematics, and failure rate data), which is why we choose this method as the preferred method to continue the course of this chapter.When to use: FMEA gives the best result when it is applied in the early stages of a process, i.e. design phase. Historically, it has been proven that the sooner a failure is detected, the less it will cost. If a failure is discovered in later stages, i.e. product development or lunch, the impact will undoubtedly be more devastating for the stakeholders. FMEA is an approach to detect failures in the earliest stages of product development. The benefits of this method over other methods (that could detect failures in the early stages as well) could be summarized as (Quality-One International, 2015):

- Offering multiple choices to mitigate the risk
- High capability of verification and validation of changes

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- Increase collaboration between the product design and the manufacturing processes, resulting in an increased information sharing through the supply chain
- Improved Design for Manufacturing and Assembly (DFM/A)
- Lower cost

Also, one needs to consider the circumstances under which FMEA is being used. This method produces best results when it is used in the following situations:

- Designing a new product, process or service
- Planning on performing an existing process in a different way, with quality improvement goals
- Understanding and eliminating possible future failures of a process, before they happen.

In the case of our chapter, since we are in the process of defining the process of supplier selection, FMEA can be regarded as the suitable approach expected to produce the required results, due to the stage of the process this problem is being studied in and also because of the benefits this specific method delivers. Thereof, with the purpose to analyze the inputs of a process, FMEAs ensure that the resultant products or services meet customer needs and expectations. When potential failure modes are identified, corrective action can be taken to eliminate or continually reduce the potential for occurrence. The FMEA approach also documents the rationale for a particular production or service process. FMEA provides an organized, critical analysis of potential failure modes of the system being defined and identifies associated causes. It uses occurrence rate and detection probabilities in conjunction with a severity criterion to develop a risk priority number (RPN) for ranking corrective action considerations, that is

$$RPN = SEV \times OCC \times DET$$

where

SEV=the severity of errors or problems in the process
OCC =the rate of errors or problems occurred
DET =the detection probabilities of errors or problems in the process
RPN =the risk priority number for corresponding problem-solving action in the process

To implement FMEA for risk management of supplier selection, we recommend that many steps should be included as followings:

1. Develop a functional block diagram to define the process of supplier selection.
2. Determine potential failure modes, that is, to identify the specific risk points occurred in the process of supplier selection.
3. Determine potential effects of the risk/failure mode, that is, to estimate the severity (SEV, ranked as 1 to 10 levels, that is, from low severity to high level) of risk occurred.
4. Determine potential causes of the risk/failure, that is, to quantify the occurrence rate (OCC, ranked as 1 to 10 levels, stands for risks occurring from low to high level) of such errors or problems happened in the process.

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5. Determine the current controls/fault detection mechanisms, that is, to evaluate the probabilities (DET, ranked as 1 to 10 levels, means low probability to a high level of risk detected) of occurring risks in the process of supplier selection.
6. Determine the Risk Priority Number (RPN), which is
   a. RPN = Severity (SEV) × Occurrence (OCC) × Detection (DET)
   b. The smaller the RPNs are the better; therefore, the larger, the worse.
7. Design the recommended corrective actions to improve supplier selection in terms of choosing the functional work process with the high-level RPNs. Engineering or technical methods might be suggested.
8. Design a strategic continuous improvement plan to eliminate the risks in the process of supplier selection. This strategic plan includes project team, target, and resources needed in the future.

PROBLEM DEFINITION

In this section, we will develop a process for supplier relationship management. It is different with a strategic process and operational one (Croxton, 2001). Interestingly, we mainly focus on establishing a supplier relationship management process on an operational level. This process contains some key components listed as followings:

- Establish criteria for categorizing suppliers.
- Evaluate each supplier by criteria established;
- Immediately renew suppliers' rating;
- Work with key suppliers as customized Product and Service Agreements (PSA);
- Implement win-win supplier relationship;
- Create an approach to share the benefit of process improvement;
- Negotiate contracts with suppliers;
- Keep on regularly effective interaction with suppliers;
- Cooperatively fulfill contracts

The operational tasks are not limited to the above list. Whereas, each task contains the potential risks which may influence the performance of supplier relationship management. For example, an overwhelmed or insufficient supplier assessment criteria might endanger implementation of retailers' business strategy; lack of instantly renewing suppliers' rating information will lead to wrong purchasing decision making; a deficiency of win-win collaboration mechanisms between the buyer and supplier might not establish a sustainable development of the business. In order to systematically analyze the risks among activities in the process of supplier selection, we introduce a process map so as to identify key risk points. As shown in Figure 3, supplier selection starts from the "Purchasing Strategy Plan" and "Potential Supplier List" as inputs until "Contract Fulfillment" after signing the purchasing contract. Based on this process, although risks might exist in each stage, they are being critically researched in the process of establishing criteria of supplier selection. They may undertake failure since potential risks are not fully taken into account. For example, a qualified supplier is experiencing financial crash after signing an official purchasing contract, because the financial risk might not be distinguished during the supplier selection. Thus, how to effectively consider potential risks as much as possible will be a crucial task in

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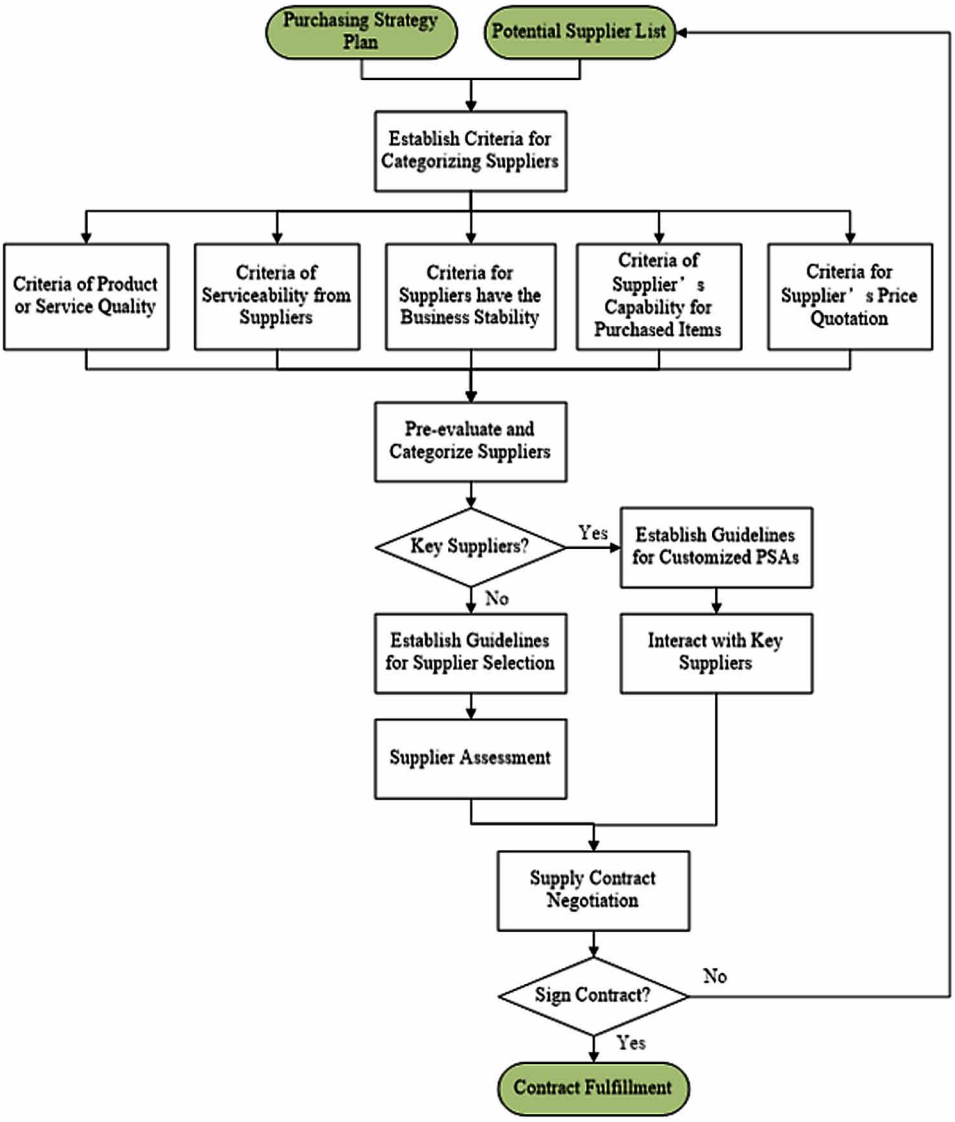
Figure 3. Supplier selection process



the following paper. However, solely relying on the process in figure 3, it would be difficult to identify specific risks and quantify how risks influence the result of supplier selection in which risks are most important to be investigated and improved.

Accordingly, in the next step, after intensive research, we will categorize potential risks and provide detailed descriptions in supplier selection. Hence, we will not only try to identify the key risk points in the process of supplier selection above, but also, intend to specify the risks that should be focused on. In order to achieve this, beginning with investigating the relationship between supply chain performance and risk management, we will develop a connection of supply chain performance and critical metric points in order to determine the corresponding awareness of potential risks.

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Table 1. Supply chain performance attributes and level 1 metrics

Performance Attribute	Performance Attribute Definition	Level 1 Metric
Supply Chain Delivery Reliability	The performance of the supply chain in delivering: the correct product, to the correct place, at the correct time, in the correct condition and packaging, in the correct quantity, with the correct documentation, to the correct customer.	Delivery Performance
		Fill Rates
		Perfect Order Fulfillment
Supply Chain Responsiveness	The velocity at which a supply chain provides products to the customer.	Order Fulfillment Lead Times
Supply Chain Flexibility	The agility of a supply chain in responding to marketplace changes to gain or maintain a competitive advantage.	Supply Chain Response Time
		Production Flexibility
Supply Chain Costs	The costs associated with operating the supply chain.	Cost of Goods Sold
		Total Supply Chain Management Costs
		Value-Added Productivity
		Warranty / Returns Processing Costs
Supply Chain Asset Management Efficiency	The effectiveness of an organization in managing assets to support demand satisfaction. This includes the management of all assets: fixed and working capital.	Cash-to-Cash Cycle Time
		Inventory Days of Supply
		Asset Turns

In terms of the SCOR model (Peter et al., 2007), it defines the metrics to evaluate supply chain performance which is called "Level 1 Metric". Table 1 lists the performance metrics with its relative performance attributes. In this paper, we consider performance metrics as the infrastructure to evaluate the risks in supply chain. It also becomes a baseline for qualifying risks analysis in supplier relationship management. That is, what causes lower supply chain performance might be considered potential risks since those causes are negatively related to achieving high-level supply chain performance.

After analyzing the relationship between risks and supply chain performance above, we proposed the metrics to describe the supplier's performance in Table 2. With this information we summarized the characteristics of evaluating supply chain performance and developed a new criteria to qualify the risks for supply chain, especially in the process of supplier selection. In that table, the specific risk might exist in the process of supplier selection (see Figure 3), and we provide detail descriptions for relevant failures.

To conclude this table, these criteria critically include the organizations' profitability, growth and stability for both retailers and suppliers; The criticality or required service level of the components purchased; The sophistication and compatibility of the supplier's implementation; The supplier's technological capability and compatibility; The volume purchased from supplier; The capability available from the supplier; The culture of innovation at supplier; The supplier's anticipated quality levels.

Although we have established the metrics to qualify and quantify the risks in supplier selection, the remaining problem is how to develop an approach to identify the risk level by using those metrics. From high priority to low, risks might be gradually eliminated or improved only when they have been rated clearly. In the following section, we will use FMEA to determine the priority level of reducing risks. The origin of FMEA can be found in the US Military Procedure (revised on 1980 as MIL-STD-1629A). This technique has been applied by NASA for the Apollo program in 1966 and adapted as another standard by Society of Automotive Engineers (SAE) in 1996 (Li et al, 2016).

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Table 2. Risks in supplier selection

Risk Attribute		Description
Quality	Durability	Product feature, sustainable service, sustainable process
	Flexibility of operation	Proper response to unexpected events, product operation
	Simplicity of operation	Standard business processes, easy to operate the product
	Reliability	Return rate, damage rate, customer compliant rate
Serviceability	Reaction to demand	Time or process of quick responsiveness
	Technical support	Technical support for presale, on-sale, after sale
	After sale service	Guarantee, warranty, service customizing, on-site support
	Flexibility for payment	Payment period, payment method, cash flow
Stability	Organization factor	Total annual sales, profits, finance, employee, location
	Quality performance	Is there a quality assurance system? ISO 9000? TQM etc.
	Technology level	How's the current technology level, development plan
	Innovation	Ability, strategy plan, financial support to do innovation
	Information sharing	Enough to know each between suppliers and buyers
	Business cooperation	How long, how have been business together
Capability	Productivity	Sales increasing, demand increasing, business expanding
	Lead time	Transportation cooperation, delivery time, order process
	Order frequency	Seasonal or predictable extra order demand
	Order amount	Order variability since customer demands variable
Price	Price reduction	Sales promotion or provide competitive pricing strategy
	Price Flexibility	Such as incentive of high order quantity or frequency

APPROACH

In the previous section, we introduced the Failure Modes and Effects Analysis (FMEA) theory and the methodology that includes eight logical steps, and also summarized the main components to achieve a high level of risk management in each stage of supplier selection process. Figure 4 has described the flow of FMEA in that process. It determines the successive research procedures for a specific case study. In order to achieve effective risk management with this FMEA method, the most significant thing to consider is to quantify the risk rates and apply corresponding countermeasures to improve them.

Combined with the process of supplier selection defined in Figure 3, in this section, we plan to develop FMEA criteria in order to apply this technique for detecting, evaluating, improving risks. As known, FMEA's final results are indicated by the number of RPNs, that is, it is composed of three factors being the severity (SEV), occurrence (OCC) and detection (DET) rate of risks. Accordingly, to apply FMEA methodology, the rating criteria should have to be established. And also, these criteria should contain the numerical, quantifiable scales to measure risks. Thereof, three criteria which are Severity Ranking Criteria, Occurrence Ranking Criteria and Detection Ranking Criteria as well will be developed.

First, in order to establish the severity ranking criteria, the severity of risks happening in the supplier selection process has to be defined. In the previous sections, risks of supplier selection have been identified and categorized. However, in this case, the main task is to determine the severity of those occurring

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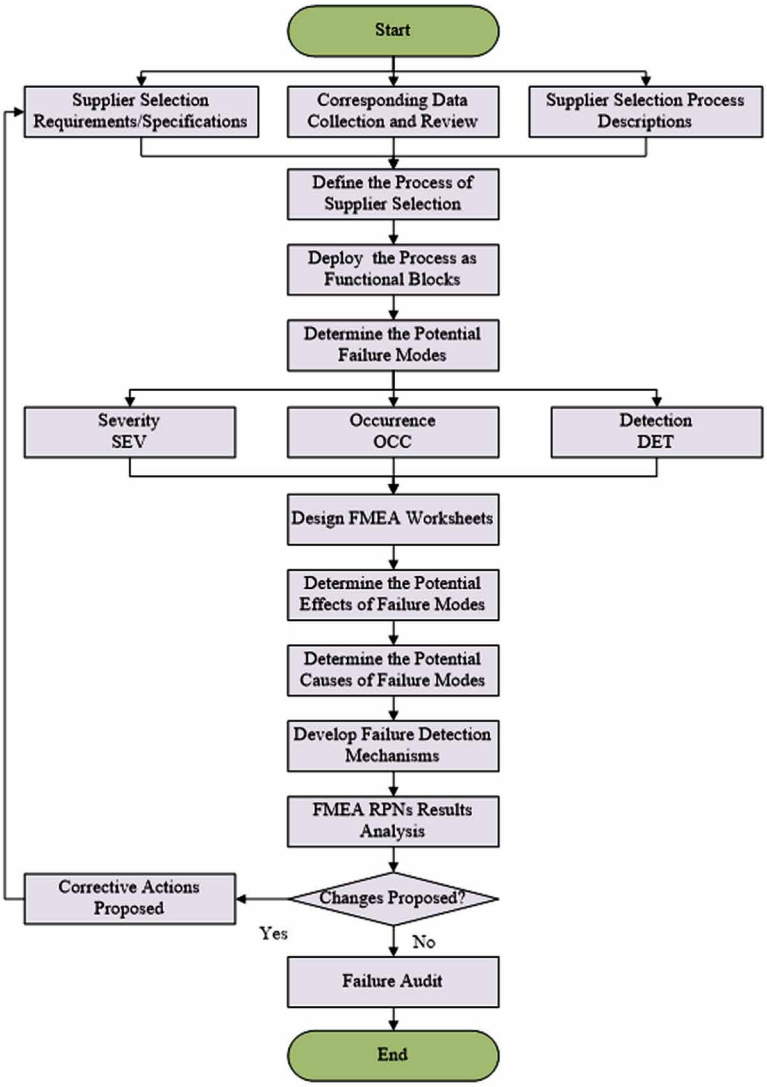
Figure 4. Supplier selection work-flow for FMEA approach



risks. In general, the results of severities led by different risks might not be the same. In other words, there are different severity levels caused by different risks happening. Moreover, the level of severity with the same risk happening is also distinguishable among different suppliers. For example, for supplier selection in retail industry, the level of severity with high stock-out rate is more significant than high return rate; definitely by different suppliers, the higher level of stock-out rate is more significant than the lower one. Therefore, in this paper, risk ranking criteria are only to sort the risks with different numerical scales by the severity degree of business damaged by risks occurring.

In Table 3, it elaborates the rank number and how to quantify the severities of risks happening. And also, the "Risk Level" might give the supplier a caution about those risks how to influence customer's satisfaction, service level, business performance. The supplier can assign the specific "Risk Level" with a specific "Rank Number" for each kind of risk. In practice, some risk ranking can be determined by

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Table 3. Severity ranking criteria

Rank Number	Risk Level	Criteria Descriptions
1–2	Minor	Failure is of such minor nature that the customer or supplier will probably not detect the failure. Or, the failure is of minor effects that the supplier's business targets will probably not be influenced.
3–5	Warning	Failure will result in slight customer annoyance and/or slight deterioration of part or product/service performance. Or, the failure will lead to a slight business margin lose, slight purchasing cost increasing and/or slight setback from achieving business targets.
6–7	Severe	Failure will result in customer dissatisfaction and annoyance and/or deterioration of part or product/service performance. Or, the failure will significantly lead to the low service level, slightly lose market share, hinder business target achievement, increase purchasing cost, etc.
8–9	Precarious	Failure will result in a high degree of customer dissatisfaction and cause non-functionality of product/service. Or, the failure will lead the results that might not be irreparable. Or, the failure will induce a huge business loss, market share loss, significant purchasing cost increasing, etc.
10	Intolerable	Failure will result in major customer dissatisfaction and cause non-system operation or non-compliance with government regulations.

historical data of supplier having long-term business cooperation with retailers. However, considering the necessity of assortment management to select new suppliers, subjectively qualify risks by "Risk Level" with risk controlling requirements, instead of quantifying risks by concrete data that they don't have since this is the first time business cooperation together.

- *Minor:* Since such risks commonly exist, they should be continuously monitored.
- *Warning:* the majority of the business might make this as a bottom line of existing risks. Above this level, there will be a higher failure in business process or supplier relationship management.
- *Severe:* This kind of risks should be selectively improved or avoided in terms of business performance requirements.
- *Precarious:* These risks should be absolutely avoided since they will harm business performance. Thus, some countermeasures should be utilized to reduce them.
- *Intolerable:* This drastic level of risks only indicates to eliminate suppliers, or they will occur when an unpredictable disaster has happened, such as an earthquake, hurricane political factors, or legislation limits.

To sum, the severity level may be determined by different rank number as one of the factors to be used to estimate final RPNs.

Secondly, we will develop a mode to decide the probability of occurring relative risks in the process of supplier selection. This mode is principally described in Table 4.

In the process of supplier selection, one of the tasks is to select the new supplier from potential tendering, and another one is to eliminate suppliers who have low product/service quality, low service level, low sales margin or out-of-business strategy plan. Thereof, similar to determining the severity of risks, buyers may rank the rate such as product failure rate, return rate, fill rate, customer complain rate and etc. should they have access to such data. Otherwise, they will quantify the probability of occur-

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Table 4. Occurrence ranking criteria

Rank Number	Occurrence Level	Criteria Descriptions
1–2	Low	An unlikely probability of occurrence during the item (product or service) operating time interval (e.g. once every season). "Unlikely" is defined as a single failure mode (FM) (e.g. the defective probability < 0.001) of the overall probability of failure during the item operating time interval. Or, the lowest occurrence rate of risks through the entire business process. For example, the buyer's inspection failure rate, return rate, fill rate, customer complains rate and so on.
3–5	Medium	A remote probability of occurrence during the item operating time interval (e.g. once a month). Remote is defined as a single FM (e.g. the defective probability > 0.001, but < 0.01) of the overall probability of failure during the item operating time interval.
6–7	High	An occasional probability of occurrence during the item operating time interval (e.g. every two weeks). Occasional is defined as a single FM (e.g. the defective probability > 0.01, but < 0.10) of the overall probability of failure during the item operating time interval.
8–9	Extremely High	A moderate probability of occurrence during the item operating time interval (e.g. once a week). Probable is defined as a single FM (e.g. the defective probability > 0.10, but < 0.20) of the overall probability of failure during the item operating time interval.
10	Unacceptable	A high probability of occurrence during the item operating time interval (i.e. once a day). High probability is defined as a single FM (e.g. the defective probability > 0.20) of the overall probability of failure during the item operating interval.

ring risks by the allowable rate number. This should give buyers more clues to determine what kinds of products of service needed.

Thirdly, to decide the rate of occurring risks detected, it is require to determine FMEA RPNs, though it should concern the characteristics of products/service, the mechanism of monitoring risks, the requirements of developing supplier relationship and so on. In this section, we try to develop a general mode to estimate the rate of risks detected, whereas the practical case of how to apply this mode on it will be proposed later.

Fourthly, to determine the priority risk that should be focused on reduction, we develop a FMEA worksheet in Table 6. As is shown, this worksheet contains the risk category, potential failure description, potential causes, effects, severity ranking number, occurrence ranking number, the detection ranking number and so on. These infrastructure data will help decide the priority risk number (RPN) so as to design the relative counter measures to lower risks.

And also, one of the most important contents in this table is the strategic or operational plan. According to this plan, retailers might organize resources to reduce those risks. For some cases, this strategic plan is required to guide the future pre-purchasing work. In addition, project teams (i.e. including procurement manager, buyers, suppliers etc.) may avoid or reduce the relevant risks in terms of the operational plan. "Verification" can be used to estimate their valuable work. This is the so-called "Continuous Improvement" plan.

In the following sections of this paper, we will set up a real case that we are executing a project to design a FMEA approach to reduce the potential risks of supplier selection for the ABC CO., LTD company (a fictitious name as the privacy policy).

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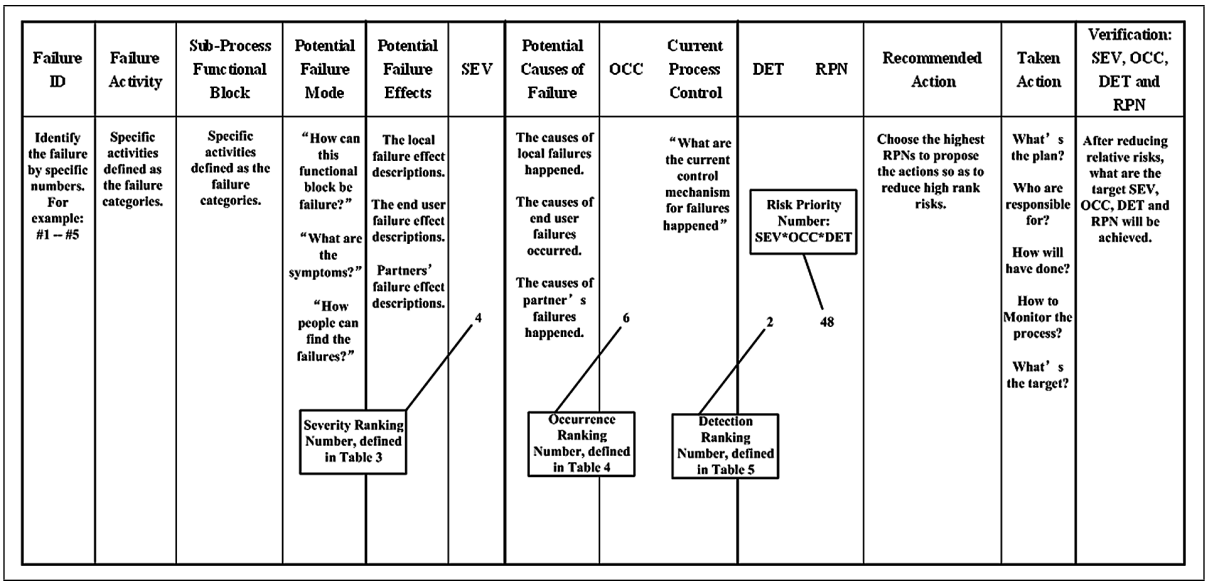
Table 5. Detection ranking criteria

Rank Number	Detection Level	Criteria Descriptions
1–2	Extremely High	Very high probability (e.g. over 95% failure or risks inspected out) that the defect or failure will be detected. Verification and/or control measures will almost certainly detect the existence of a deficiency, defect, failure or risk.
3–5	High	High probability (e.g. the failure > 80%, but < 95% might be inspected out) that the defect will be detected. Verification and/or controls measures have a good chance of detecting the existence of a deficiency, defect, failure or risk.
6–7	Medium	Moderate probability (e.g. the failure > 70%, but < 80% might be inspected out) that the defect will be detected. Verification and/or controls measures have a good chance of detecting the existence of a deficiency, defect, failure or risk.
8–9	Low	Low probability (e.g. the failure > 50%, but < 70% might be inspected out) that the defect will be detected. Verification and/or controls measures have a good chance of detecting the existence of a deficiency, defect, failure or risk.
10	Slight	Very low (zero, or e.g. the failure < 50% might be inspected out) probability that the defect will be detected. Verification and/or controls measures have a good chance of detecting the existence of a deficiency, defect, failure or risk.

CASE STUDY

Case Description: *ABC Co., Ltd.* commenced its business in Shanghai twenty years ago. During the past years through direct operations, franchises, merger, and acquisitions, it has developed into a nationwide chain retail operator with a full range of retail segments in China. As of December 31st 2008, the company and its subsidiaries operated a total of 3,872 outlets (excluding those operated by the Company's associated companies) spanning in 20 provinces and municipalities across the nation. The Company

Table 6.



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continued to maintain its leading position in the fast-paced environment of consumer goods (FMCG) chain in the People's Republic of China. ABC is one of the companies listed on Hongkong Stock Exchange as the retail operator.

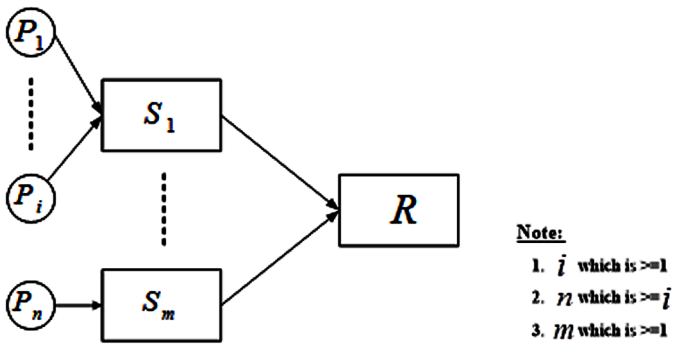
The Group operates in three main segments of retail outlet brands, namely hypermarkets, supermarkets and convenience stores, catering for the diverse needs of consumers. In one of ABC's branches (named BA in this paper), its procurement department is dependently managing over 2275 suppliers and purchasing approximately 100,000 types of commodities in a year. In the purchasing department, there are hundreds of employees working on supplier selection, supply contract negotiation and assortment management etc. BA's total sales margin is over 8 billion in 2008. Moreover, in 2009, the total value of purchasing commodities on contracts is over 9.3 billion managed by the procurement department (The financial report, 2009: data can be provided with privacy agreement research is of interest). Also, data from 2009 showed that 115 out of 2275 suppliers have been eliminated. Although this represents only 5.05%, it still indicates that there is high variability of BA's supplier relationship. Thereof, it is crucial to design an approach to improve supplier relationship management so as to develop a stable partnership with suppliers. With BA placed under such pressure, therefore, how to effectively manage its suppliers, how to avoid the potential risks in supplier selection, and how to establish the sustainable development for its business, become imperative and challengeable tasks. Thus, for the rest of the present paper, FMEA as a proposed approach will be implemented to help buyers reduce the potential risks in their supplier selection process and a strategic plan will be suggested.

FMEA APPROACH IMPLEMENTATION

As described above, procurement process map and supplier selection process have been defined, and also criteria of severity (Table 3), occurrence (Table 4) and detection (Table 5) have been established. Hence, for evaluating supply risks in company BA, we will describe cases of how to apply FMEA approach under different situations. There are two assumptions to be proposed, and also the supplier-retailer relationship has shown such assumptions in Figure 5.

Assumption 1: There is more than one supplier to supply products, and also there is more than one product selling being sold by the retailer.

Figure 5. Supplier-retailer relationship in BA



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Assumption 2: Suppliers might supply the same product which may be produced by different manufacturers, but they provide the retailer with different prices and quality characteristics to choose among those products.

Under such assumptions, we will describe the different cases in which suppliers supply products to the retailer.

Case 1: One supplier supplies only one product (such as supplier S_m only supply product P_n).

Only one FMEA worksheet is required for the product. Then, the retail ranks the RPNs of this product. The retailer might only select the risk with the highest RPN to improve it with the supplier, or develop collaborative improvement plans related to all / part of corresponding RPNs for P_n.

Case 2: One supplier supplies more than one product (such as supplier S_1 supplies i kinds of products).

Each product should have a unique FMEA worksheet. The supplier can improve the performance for one of the products depending on the highest RPN among all FMEA worksheets; they can either improve all products from the higher RPN to lower by ranking the highest RPN of each FMEA worksheet.

Case 3: Many suppliers supply products to a retailer (such as supplier S_1 to supplier S_m supply products to retailer R).

Each supplier should have an FMEA worksheet. It doesn't matter how many products a supplier supplies to the retailer. The retailer can choose the supplier who has the highest RPN among all sheets to improve its performance; either they can collaboratively develop the plans with suppliers from the higher RPN to the lower.

In this literature, we will propose an example of how to apply this FMEA approach to reduce potential risks. In this example, Table 7 has shown the details of evaluating this unique product's FMEA worksheet with Case 1.

We have assessed five characteristics of this supplier's performance, "Quality" attributes, "Serviceability" features, "Stability" characters, "Capability" factors, and "Price" merits as well. In this example of FMEA worksheet, we use those italics to explain how to correspondingly mark the supplier's performance. The file "FM.x.y" (where "x" indicates the "Failure ID", and "y" indicates the "Failure Activity") records the "Potential Failure Mode" which is to identify the relative failures.

The file "FE.x.y.s" (where "x" indicates the "Failure ID", and "y" indicates the "Failure Activity") records the "Potential Failure Effects" influenced supplier's performance; that is, those risks will lead to these "Potential Failure Effects" when supplier ignores to reduce them. Likewise, the file "FE.x.y.b" records the "Potential Failure Effects" influenced buyer's performance; that is, those risks will lead to these "Potential Failure Effects" when buyer ignores to reduce them. Furthermore, the file "FE.x.y.c" records the "Potential Failure Effects" influenced customer's performance; that is, those risks will lead to these "Potential Failure Effects" when supplier ignores to reduce them.

The file "FC.x.y.s", "FC.x.y.b", and "FC.x.y.c" have the approximate definitions. They document the descriptions of "Potential Causes" with the causes that lead to failures (i.e. high risks). Since the retailer might not recognize those potential risks, we can definitely know that the failures have been caused by the supplier (detail information/data recorded in file FC.x.y.s), or the retailer (detail information/data recorded

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Table 7a. FMEA worksheet for evaluating single product of a supplier

Failure ID	Failure Activity	Sub-Process Functional Block	
#1 Quality	1. Durability of Product	*Estimating the product quality, indicate this blank as "Durability", "Flexibility", "Simplicity", and "Reliability".*	Durability
	2. Flexibility of Operation		Flexibility
	3. Simplicity of Operation		Simplicity
	4. Reliability of Product		Reliability
#2 Serviceability	1. Reaction to Demands	*Estimating the service ability, included "Reaction", "Support", "Service", and "Payment".*	Reaction
	2. Technical Support		Support
	3. After Sale Service		Service
	4. Flexibility for Payment		Payment
#3 Stability	1. Organization Factor	*Estimating the business stability by determining the "Organization", "Quality", "Technology", "Inovation", "Information", and "Collaboration".*	Organization
	2. Quality Performance		Quality
	3. Technology Level		Technology
	4. Innovation		Inovation
	5. Information Sharing		Information
	6. Business Cooperation		Collaboration
#4 Capability	1. Productivity	*Estimating the supply capability with "Productivity", "Lead Time", "Order Processing Cycle Time", and "Order Batch".*	Productivity
	2. Lead Time		Lead Time
	3. Order Frequency		Order CT
	4. Order Amount/Batch		Order Batch
#5 Price	1. Price Reduction/Fluctuatic	*Estimating the sub-failure of price, indicate as "Price Reduction/Fluctuation", and "Price Flexibility".*	Reduction
	2. Price Flexibility		Flexibility

in file FC.x.y.b), or coming from customer's side (detail information/data recorded in file FC.x.y.c). The file "PC.x.y" records the "Current Process Control" mechanisms in current buyer-supplier relationship management system. In these files, we have documented methods for how to monitor failures/risks, what countermeasures should be implemented as if failures are being happened, who will be responsible, etc.

The file "GAP" and "DAP" have individually described a high level action plan and a detailed execution plan. Those action plans are the corresponding outcomes to reduce the risks by RPNs.

In this example, as a prerequisite to collect the necessary data needed for implementing the FMEA approach, BA might achieve them from its IIS (Integrated Information System), such POS data, sup-

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Table 7b. FMEA worksheet for evaluating single product of a supplier

Potential Failure Mode (FM)		**Potential Failure Effects (FE)**	
Identifying the failures of "What", "How", "Why", "Where", "When", etc., Recorded as file FM.1.x	FM.1.1	*To identify the failure effects for Supplier, Buyer, and the Customer. Indicated as FE.1.x.y*	FE.1.1.s, FE.1.1.b, FE.1.1.c
	FM.1.2		FE.1.2.s, FE.1.2.b, FE.1.2.c
	FM.1.3		FE.1.3.s, FE.1.3.b, FE.1.3.c
	FM.1.4		FE.1.4.s, FE.1.4.b, FE.1.4.c
Identifying the failures of "What", "How", "Why", "Where", "When", etc., Recorded as file FM.2.x	FM.2.1	*To identify the failure effects for Supplier, Buyer, and the Customer. Indicated as FE.2.x.y*	FE.2.1.s, FE.2.1.b, FE.2.1.c
	FM.2.2		FE.2.2.s, FE.2.2.b, FE.2.2.c
	FM.2.3		FE.2.3.s, FE.2.3.b, FE.2.3.c
	FM.2.4		FE.2.4.s, FE.2.4.b, FE.2.4.c
Identifying the failures of "What", "How", "Why", "Where", "When", etc., Recorded as file FM.3.x	FM.3.1	*To identify the failure effects for Supplier, Buyer, and the Customer. Indicated as FE.3.x.y*	FE.3.1.s, FE.3.1.b, FE.3.1.c
	FM.3.2		FE.3.2.s, FE.3.2.b, FE.3.2.c
	FM.3.3		FE.3.3.s, FE.3.3.b, FE.3.3.c
	FM.3.4		FE.3.4.s, FE.3.4.b, FE.3.4.c
	FM.3.5		FE.3.5.s, FE.3.5.b, FE.3.5.c
	FM.3.6		FE.3.6.s, FE.3.6.b, FE.3.6.c
Identifying the failures of "What", "How", "Why", "Where", "When", etc., Recorded as file FM.4.x	FM.4.1	*To identify the failure effects for Supplier, Buyer, and the Customer. Indicated as FE.4.x.y*	FE.4.1.s, FE.4.1.b, FE.4.1.c
	FM.4.2		FE.4.2.s, FE.4.2.b, FE.4.2.c
	FM.4.3		FE.4.3.s, FE.4.3.b, FE.4.3.c
	FM.4.4		FE.4.4.s, FE.4.4.b, FE.4.4.c
Identifying the failures of "What", "How", "Why", "Where", "When", etc., Recorded as file FM.5.x	FM.5.1	*To identify the failure effects for Supplier, Buyer, and the Customer. Indicated as FE.5.x.y*	FE.5.1.s, FE.5.1.b, FE.5.1.c
	FM.5.2		FE.5.2.s, FE.5.2.b, FE.5.2.c

plier assessment data, distribution data, customer service management (CSM) data, financial settlement records, and so on.

However, there is an excessive amount independent data to make the decision of supplier selection, even though BA has a high-level Decision-making Support System (DSS) to help senior manager select key suppliers. Thereof, buyers (e.g. senior buyer, junior buyer and buyer assistant) are difficult to select the right suppliers only depending on the supplier assessment data provided by IIS. To use the FMEA approach combined with supplier assessment data and information gathered from suppliers, buyers could improve the efficiency and accuracy to select high deserved suppliers.

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Table 7c. FMEA worksheet for evaluating single product of a supplier

SEV	Potential Causes of Failure (FC)		OCC	Current Process Control (PC)		DET	RPN
2	*To identify the failure causes from Supplier, Buyer, and the Customer. Indicated as FC.1.x.y*	FC.1.1.s, FC.1.1.b, FC.1.1.c	3	*To identify the current system/process control mechanism for failures. Indicated as PC.1.x*	PC.1.1	1	6
4		FC.1.2.s, FC.1.2.b, FC.1.2.c	2		PC.1.2	2	16
5		FC.1.3.s, FC.1.3.b, FC.1.3.c	4		PC.1.3	1	20
3		FC.1.4.s, FC.1.4.b, FC.1.4.c	1		PC.1.4	6	18
1	*To identify the failure causes from Supplier, Buyer, and the Customer. Indicated as FC.1.x.y*	FC.2.1.s, FC.2.1.b, FC.2.1.c	2	*To identify the current system/process control mechanism for failures. Indicated as PC.2.x*	PC.2.1	2	4
2		FC.2.2.s, FC.2.2.b, FC.2.2.c	3		PC.2.2	3	18
2		FC.2.3.s, FC.2.3.b, FC.2.3.c	4		PC.2.3	2	16
1		FC.2.4.s, FC.2.4.b, FC.2.4.c	1		PC.2.4	1	1
6	*To identify the failure causes from Supplier, Buyer, and the Customer. Indicated as FC.3.x.y*	FC.3.1.s, FC.3.1.b, FC.3.1.c	1	*To identify the current system/process control mechanism for failures. Indicated as PC.3.x*	PC.3.1	6	36
5		FC.3.2.s, FC.3.2.b, FC.3.2.c	3		PC.3.2	3	45
4		FC.3.3.s, FC.3.3.b, FC.3.3.c	2		PC.3.3	5	40
7		FC.3.4.s, FC.3.4.b, FC.3.4.c	2		PC.3.4	8	112
7		FC.3.5.s, FC.3.5.b, FC.3.5.c	4		PC.3.5	3	84
3		FC.3.6.s, FC.3.6.b, FC.3.6.c	5		PC.3.6	4	60
3	*To identify the failure causes from Supplier, Buyer, and the Customer. Indicated as FC.4.x.y*	FC.4.1.s, FC.4.1.b, FC.4.1.c	2	*To identify the current system/process control mechanism for failures. Indicated as PC.4.x*	PC.4.1	2	12
2		FC.4.2.s, FC.4.2.b, FC.4.2.c	4		PC.4.2	2	16
2		FC.4.3.s, FC.4.3.b, FC.4.3.c	5		PC.4.3	5	50
1		FC.4.4.s, FC.4.4.b, FC.4.4.c	4		PC.4.4	6	24
1	*To identify the failure causes from Supplier, Buyer, and the Customer. Indicated as FC.5.x.y*	FC.5.1.s, FC.5.1.b, FC.5.1.c	6	*To identify the current system/process control mechanism for failures. Indicated as PC.5.x*	PC.5.1	1	6
4		FC.5.2.s, FC.5.2.b, FC.5.2.c	4		PC.5.2	4	64

In Table 7, this example shows how to estimate the risks from ABC Inc. The FMEA approach considers the risks of product quality factors, serviceability, business stability, production capability, and price factors so that buyers can determine which risks will highly influence the performance of supplier and if those high rank of risks could be reduced. Furthermore, corresponding causes and effects of potential risks have been identified. Thus, buyers can benefit from the results in order to select this supplier or eliminate it. The highest RPN=112 means that the potential "Innovation" ability of the supplier is very low, and also current "Information Sharing" RPN=84 indicates the supplier might not openly share information with retailer due to technical or systematic limitations. Moreover, the "Price Flexibility" RPN=64 indicates this supplier is confined to make any markdown or sale for some reasons.

By utilizing this FMEA worksheet, we can not only identify the potential risks and their relevant causes and effects, but also, we can develop an action plan to reduce corresponding risks by assigning

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Table 7d. FMEA worksheet for evaluating single product of a supplier

Recommended Action (GAP)	Taken Action (DAP)	Verification: the number of SEV, OCC, DET, and RPN			
		2	3	1	6
		4	2	2	16
		3	4	1	12
		3	1	6	18
		1	2	2	4
To design this high level action plan for the specific failure(s) which has/have the highest RPN(s) in order to reduce the corresponding risks. This high level action plan might be short in words, or might be in detail. How to develop the action plan, it will depend on the risk complexity, target requirment, and etc. This plan should describe those included "Risk Description", "Failure Effects", "Failure Causes", "RPN Target to be reached", and so on.		2	3	3	18
		2	4	2	16
	This is to design the detail action plan(s) (DAP). Each plan may contains "Internal File Number", "Plan Abstract", "Who are responsible for?", "How will have done?", "What are the process?", "How to monitor the process", "How to audit the results?", and etc.	1	1	1	1
		3	1	3	9
		4	3	3	36
		4	2	4	32
		3	2	3	18
		2	4	3	24
		3	4	4	48
		3	2	2	12
		2	4	2	16
		2	3	5	30
		1	4	2	8
		1	3	1	3
		3	2	4	24

resources, such as project team, investment, equipment and so on. In Table 7, ideally, the targets of SEV (value is “3”), OCC (value is “2”), DET (value is “3”), and RPN (value is “18”) should be achieved after implementing the improvement plan. It is obvious that RPN “18” is much lower than RPN “112” through reduced corresponding risks.

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To conclude this example, the risks from this supplier indicate that a strategic partnership by R&D capability might not be developed and the ability to implement price promotion is limited. In order to prove this conclusion, buyers should investigate more on this company's business strategy plan, technical development plan etc.

PROPOSED IMPROVEMENT

The FMEA approach designed for BA's procurement department efficiently identifies, monitors, and evaluates risks in supplier relationship management process. With the situation in BA, buyers are managing a large number of suppliers and products. Each year, they have to purchase the commodities that BA's business strategy requires. Possibly, new suppliers might be needed to supply those commodities by the requests of assortment management. And also, it is required to eliminate the products or suppliers with high potential risks to improve business performance. FMEA can be directly applied to select suppliers from potential supplier list or from tendering suppliers. For current supplier assessment, a part of supplier relationship management is to identify key suppliers so as to establish strategic partnerships with and the corresponding improvement should be implemented to do so. Hence, to sum up, this approach can be applied in the following areas:

- Pre-assessement of supplier's risks to provide potential suppliers
- Assessing the risks of current suppliers in order to identify the performance rank of suppliers
- Managing key suppliers by periodically assessing their associated risks
- Providing accordance to eliminate suppliers
- Identifying the task sequence of improving supplier relationship management in terms of RPNs from high to low

Therefore, to implement the FMEA approach in supplier relationship management, either for selecting new suppliers or assessing current suppliers, we suggest a continuous improvement plan as follows:

1. Collect the data by IIS as the infrastructure information of supplier selection.
2. Research and identify the potential risks in supplier selection.
3. Diversely discover the supplier's data for risk analysis, such as business performance ranked by the third parties, financial reports of shareholders, questionnaire surveys, customer feedback, etc.
4. Periodically assess the risks by FMEA approach to rank suppliers or rank the potential suppliers by the RPN results.
5. According to the continuous improvement action plan in FMEA, frequently monitor and audit the risk status in supplier in order to maximally reduce potential risks in supplier selection.
6. Review current RPNs (including SEV, OCC and DET) to the targets, and then dynamically adjust action plans to achieve those targets.
7. Suitably store all the risk assessment records so as to discover the improvement or transformation of suppliers' performance. To do so, the firms might forecast the trend of the supplier's business changing to avoid the risks that might happen in future.
8. Implement collaborative purchasing management with strategic suppliers by sharing the risk evaluation results to achieve sustainable supply chain management.

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CONCLUSION

In the present paper, we reviewed risks in supply chain management particularly in the procurement of retail industry. After establishing the criteria of estimating risks in the supplier selection stage of procurement management, an FMEA approach was been proposed to identify, qualify, quantify and reduce risks in the process of supplier selection. This approach is developed for the procurement department of BA (mentioned in the case study section) in order to help buyers manage their supplier relationship more efficiently and to provide a DSS tool. There is a short example mentioned in the case study indicating how this approach can be applied in real world scenarios and how powerful it can be for to identifying, evaluating, monitoring and reducing risks.

Since this project was practically implemented, detailed data should have to follow the privacy of BA's business security requirements. Hence, in this paper, we mainly described the approach and powerful functions. To verify, in the short example of FMEA worksheet we used the pseudo data in order to protect privacy and explain the procedures of implementing the the FMEA approach.

In the end, a proposed improvement plan for general uses of supplier selection by FMEA approach in retail industry has been elaborated.

Although this paper is considered infrastructure research in risk management for supplier relationship management in supply chain, it provides a crucial insight to pursue deep study in risk management in purchasing. In future studies, we will develop more practical tables and clues to implement FMEA approach more efficiently so that the buyer could further utilize it to improve the performance of their purchasing work. There is plenty of room for future research to be considered in this area. With regards to this chapter, we will summarize the relevant research gap in two main directions. First, there is still significant research gap in the processes of computation of the FMEA rankings. Flexible ranking systems and standard rubrics can be considered to formalize the FMEA process in the supplier selection problem (Li et al, 2016). Second, software development can be considered as a very efficient tool to support the documentation and evaluation efforts in FMEA. In addition, it can also be implemented to suggest potential control strategies faster and with lower costs for ultimately minimizing the risks of particular suppliers (Li et al, 2016). There still seems to be a research gap in the detailed use software development as a tool for supplier risk management.

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KEY TERMS AND DEFINITIONS

FMEA (Failure Modes and Effects Analysis): Also called "failure modes," FMEA is an advanced Six Sigma tool applied on manufacturing or service industry to detect the potential risks in processes, and to determine relevant actions to implement continuous improvement.

Risk (in Supply Chain): A negative deviation from the expectation of valuing a certain performance measure, resulting in negative consequences for the focal firm or a certain supply chain facility.

SCOR (Supply Chain Operations Reference): Supply-chain operations reference model is a reference model identified by the Supply Chain Council as the standard reference for supply chain management.

SCRM (Supply Chain Risk Management): The management of the supply chain risks through coordination or collaboration among the supply chain partners, so as to avoid business failures and ensure profitability and continuity.

SRM (Supplier Relationship Management): All activities regarding strategically planning and management of interactions with external organizations that supply goods and/or services to an organization with the goal of maximizing the value of those interactions.

Supply Chain: All interactions involved and adding value to the whole processes between the point of production of goods or services and the point of delivering those goods or services to the end customer.

Vulnerability (in Supply Chain): Point(s) of weakness or a possible thread to the supply chain that makes it susceptible to a possible loss.

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Chapter 18
Operations Planning in Carsharing Systems:
A Literature Review of Problems, Issues, and Solutions

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ABSTRACT

Shared mobility systems such as carsharing provide significant social and environmental benefits by reducing the number of vehicles used in the urban transport network. The carsharing systems are facing many challenges from the design to operation stages. In the design and strategic management level, it is important to find the best location for the stations, a minimum number of vehicles and a minimum number of operating staff, and in the operation stage, the most important problem is to relocate the vehicles moved by the members among the network to maximize the satisfied demands while the system is still economical. Effective and efficient optimization technology that can respond to user's demand is one of the necessary components for a successful carsharing system. The authors survey the related operations research models in the academic literature proposed to model different aspects of carsharing systems from a strategic and operational point of view to find the gaps and propose opportunities for new research.

INTRODUCTION

Shared mobility system is generally defined as short-term vehicle access among a group of members who share a vehicle fleet that is maintained, managed, and insured by a third-party organization (Shaheen, Chan, & Micheaux, 2015). As an alternative transportation solution, shared-use mobility in the forms of carsharing or bike sharing grabbed the attention of experts to face the known problems of traffic congestion, air pollution and vehicle related accidents (Omrani, Awasthi, Ion, & Trigano, 2009; Almeida, Silva, & Leite, 2017).

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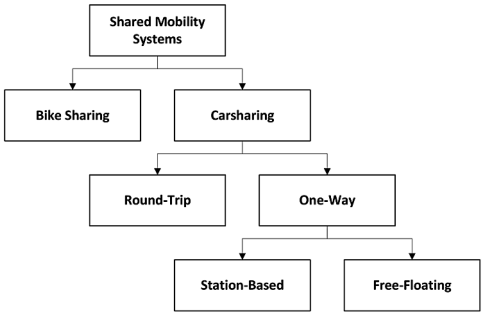
Figure 1. Different types of shared mobility systems



The shared-use mobility is typically provided through self-service vehicle access on a 24h basis for short-term trips. Rates include fuel, insurance, and maintenance. There are several models: roundtrip car or bike sharing (vehicles are accessed and returned to the same location), peer-to-peer carsharing (shared use of privately-owned vehicles operated by a third-party organization), one-way vehicle sharing, and a few other methods (Shaheen, Cohen, & Jaffee, 2018). Different types of mobility shared systems shown in Figure 1.

Car-based shared mobility systems are divided into two main categories: Round-trip and One-way systems. Round-trip carsharing systems are defined as schemes providing short-term access to a vehicle for members. The system has fixed locations for vehicle pick-up and the members can have access to cars with prior booking. The users must return the car to the original pick-up station according to their confirmed itinerary. A rapidly emerging mobility sharing system is one-way carsharing, which does not require users to return a vehicle to the same location from which it was accessed, thus allowing users to make one-way trips. Technology has played a major role in the growth of one-way carsharing, including smartphone applications, keyless vehicle access, in-vehicle and mobile global positioning system (GPS) receivers, and hybrid and electric vehicles (EVs). One-way carsharing presents unique challenges, such as vehicle rebalancing and parking management. Free-float carsharing system is very close to one-way systems in definition. The main differences in the working principle of free-float carsharing when comparing with classic one-way carsharing are: (a) Pick up / drop off a car is possible freely in a defined zone of a city, as cars have no fixed positioning, (b) Booking is just possible on the spot, preferably by smart phone app showing the position of the next available cars (but this is also feasible via internet or by phone call), and (c) The renting duration is fully flexible and does not need to be indicated when booking. Renting ends when dropping off the car.

In this survey we have focused on one-way carsharing issues and solutions.

BACKGROUND AND REVIEW PROCESS

Historical Background

One-way carsharing began in Europe in the 1970s through experimental programs. The earliest small-scale carsharing system known as Sefage was founded in Zurich, Switzerland in 1948. This system along with Procotip which was launched in 1971 in Montpellier, France, Witkar which was opened in Amsterdam

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in 1974 were failed because they were not economically successful (Biau, 1991). In late-1990s, Liselec launched in La Rochelle, France (sponsored by Peugeot-Citroen) to again test Electrical Vehicle (EV) use in one-way carsharing. The program was successful and still exists today as Yelo mobile (Shaheen et al., 2015). Praxitele launched in October 1997 in a Paris suburb as an experiment with Renault Clio EVs (Shaheen et al., 2015).

In 1998, Honda Motor Company announced the development the Intelligent Community Vehicle System (ICVS). In June 2003, Honda also launched Honda DIRACC in Singapore. The members could access cars without a reservation and leave then at any other station in the area (Shaheen et al., 2015).

CarLink I experiment were initiated in the U.S. in January 1999, facilitated one-way trips between train stations and home- and work-based trips. CarLink II followed this project and was based at the Caltrain station in Palo Alto, California from July 2001 to June 2002. At the end of the CarLink II pilot, Flexcar took over the service in July 2002. However, it finished operations in July 2003 (Shaheen et al., 2015).

Car2Go founded in Stuttgart, Germany in 2008 as a subsidiary of Daimler AG providing carsharing services in European and North American cities. As of June 2017, car2go is the largest carsharing company in the world with 2,500,000 registered members and a fleet of nearly 14,000 vehicles in 26 locations in North America, Europe and Asia (car2go N.A. LLC, 2017).

Review Process

A structured approach was used to determine the source of materials for review. The peer-reviewed literature was the main source of information about principles and methods for design and operation of carsharing systems.

Searches for peer-reviewed journal articles and dissertations were conducted using the Google Scholar search engine and the searches were limited to research published in English. We also used "backward approach" to find any important references that had been missed in the online searches but were cited by key journal articles. A third source of research papers identified by using of citation indexes to identify articles citing important references; that is known as "go forward" approach. Inclusion/exclusion criteria were used in the decision tree for selecting articles to include or exclude in the literature review. We included documents that discussed user's demand estimation based on operating parameters of the system and vehicle and staff relocation strategies. We also included the papers that provided strategies for designing the system regarding the fleet size, required staff number and parking locations as well as the articles addressing the operating policies like initial distribution of the fleet and effect of price incentives on the system performance. We excluded documents that were not in English and papers on social aspects of the carsharing systems.

LITERATURE REVIEW

One of the key issues of design and development of any urban transport system is anticipating the demand for the service. In this section, we will review the literature addressing this issue and then extend our work to strategic issues of designing such a service by looking into the location planning, fleet size, and parking capacity. From the operational point of view the main issue of the one-way car-sharing systems, either station-based or free-float systems, is rebalancing the system such in order to maximize the performance of the system. In part C of this section we review the research addressing the system

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rebalancing. Finally, the problem of designing the charging station network to serve the carsharing systems utilizing EVs is addressed.

Demand Modeling

Catalano, Lo Casto, and Migliore (2008) studied Palermo city in Italy and constructed a modeling tool to forecast choices between traditional modes of transport and newly carsharing and carpooling modes. A multinomial logit model was presented and the Stated Preference (SP) survey technique was used to estimate model parameters. The respondents belong to households owing at least two cars and they could give up owing a vehicle and use the carsharing service.

Stillwater, Mokhtarian, and Shaheen (2009) compared the use of carsharing vehicles over a period of 16 months with the built environment and demographic factors for an urban US carsharing operator. They used regression analysis to explain the average monthly hours of carsharing use and concluded that the most significant variables were: street width, the provision of a railway service, the percentage of drive-alone commuters, the percentage of households with one vehicle, and the average age of the stations. The percentage of drive-alone commuters, street width, and heavy rail availability were negatively related to carsharing, that is, the higher these factors the lower the demand. The percentage of households with one vehicle, the average age of the stations, and light rail only availability was positively related to carsharing use, meaning that the higher these factors the higher the demand.

Morency, Habib, Grasset, and Islam (2012) studied the behavior of carsharing user. They used the empirical data from Communauto CSO in Montreal to calculate the probability of being active in any month as well as using the service in the month for each member over a period of 40 months between 2005 and 2008. By using random utility-based approach the utility of using the service, the proposed models reveal that the activity persistency of members is positively linked to previous behaviors for up to 4 previous months, and that the influence of previous months weakens over time. It also showed that the gender, age, and ethnicity of the members influence their behaviors.

A study by Müller, Correia, and Bogenberger (2017) analyzed the booking data, land use, and census datasets to predict the demand of free-floating carsharing systems. The booking data measures the actual demand of the system while the land use and census data describe the activities performed in different areas in a city. Regression models are used to find the relation between the number of carsharing trips starts in any districts and the population living in each neighborhood. Several parameters studied and the results have been discussed for the datasets from Berlin, Germany. Finally, the models is used to predict the demand in Munich and Cologne, Germany. The transferred model predicted booking hot spots successfully but some additional local effects such as agreements between CSOs and companies, specific parking restrictions that are not considered in the model made the model locally.

Qian et al. (2017) analyzed data provided by Chefenxiang CSO in Hangzhou, China and clustered the members using patterns into five clusters and find out that long-term frequent heavy members were inferred as stable users for commute or business purpose. Members' temporal and spatial behavior characteristics such as number of using records, number of distinct pick-up locations, using time intervals, and time duration of each reservation are selected. A Two-step Cluster Analysis procedure to find the optimal number of clusters automatically was used to classify carsharing use patterns. The validity of the clusters was assessed by the one-way Analysis of Variance (ANOVA) method. Members travel features are then discussed for the obtained five clusters.

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Table 1. Summary of carsharing demand modeling research

Reference	System Type	Modeling Technique
(Catalano et al., 2008)	Station-Based	Stated Preference (SP) technique
(Stillwater et al., 2009)	Station-Based	Regression based GIS Model
(Morency et al., 2012)	Station-Based	Two-Stage Microsimulation
(Müller et al., 2017)	Free-Float	Negative Binomial Regression
(Qian et al., 2017)	Station-Based	Clustering Method

Location Planning and Stations Capacity

A global approach to develop the decision aid tool is presented by Boussier, Ion, Breuil, and Benhabib (2005). In this global approach conceptual modelling, implementation and software development is seen as a cyclical process and each step has a validation phase. A fuzzy modelling technique is used to describe behavioral process with uncertain variables. In order to describe the vehicles flows, a fuzzy model to evaluate an "affinity" indicator between two stations as function of the accessibility to an urban area, the attractiveness and the cost of the travel between these two stations is proposed. The model can be used as a strategic decision-making tool to indicate the attractiveness of the station locations and user demands.

Cheu, Xu, Kek, Lim, and Chen (2006) develop trip-forecasting models to estimate the number of vehicles available from a station at a particular time of a day. Two different modelling approaches are developed and tested with the data from Honda ICVS system. Inspired by biological neurons within the human brain, a suitable Multi-Layer Perceptron (MLP) network is proposed in this research. The MLP consists of a single input layer (with 3 neurons), where the influencing input variables are entered. The inputs are net flow at the same station at: (1) the 3-h period that has just ended in the past 1 h, (2) the same period on the previous day, and (3) the same period on the same day of the previous week. The output layer has only one neuron with a linear transfer function to forecast the net flow in a 3-h period. There is only one hidden layer. The number of neurons in the hidden layer varied in the different MLPs. MLPs with different numbers of neurons in the hidden layer were trained with 6 months (months t-7 to t-2) of data, and the one that produced the most accurate net flow forecast for the following month (month t-1) of validation data was selected to forecast for the subsequent month (month t) for evaluation purposes. Given that the evaluation was performed for 6 months of ICVS operations, the number of MLPs eventually selected to perform forecast at each port was 6 months × 24 periods/day = 144 per port. In most cases, each training data set consists of 6 months × 30 days/months = 180 training data points. Neurons are connected only at adjacent layers. In this research, the hyperbolic tangent or "tanh" transfer function is used for the neurons in the hidden layer. A linear transfer function was used for the neurons in the input and output layers. The scaled conjugate gradient training method with Levenberg–Marquardt algorithm was chosen for its fast convergence without overtraining. The batch training method whereby weights and biases were updated only after all inputs and targets were presented once was used.

As an alternative modelling approach, a Support Vector Machine (SVM) is also developed in (Cheu et al., 2006). The SVM learning algorithm directly seeks a separating hyperplane that is optimal by being a maximal margin classifier with respect to the training data. For nonlinearly separable data, SVM uses the kernel method to transform the original input space, where the data is nonlinearly separable, into a higher dimensional feature space in which an optimal linear separating hyperplane is constructed.

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Like the MLPs, a total of 180 SVMs were trained. In SVM training, a Genetic Algorithm (GA) is used to specify parameter values. For the training or development of the MLP and SVM models, the prior month's data were used as the validation set, and the previous 6 months' data were used as the training set. The average absolute error and maximum absolute error, from the forecasts of all the 3-h periods within each month, were generated for comparison purposes. In comparison, the MLPs return a lower monthly average absolute error range of 0.38 to 0.73 vehicles/3 h and a monthly maximum absolute error range of 1.54 to 2.58 vehicles/3 h. The monthly average absolute errors of the SVMs are slightly higher than those of the MLPs, but differences in the monthly maximum absolute errors also are higher. The results suggest that, on average, MLPs provide more accurate forecasts than SVMs do.

The location problem for carsharing stations in a city studied in (Awasthi, Chauhan, Hurteau, & Breuil, 2008). The authors used Analytical Hierarchy Process (AHP) multi-criteria decision-making method to quantify relative priorities of the selection criteria for determining the carsharing locations. Since the criteria can be either quantitative or qualitative or both in nature, the second problem treated is the development of a common scale for the measurement and evaluation of different type of criteria. The third problem is related to the allocation of ratings or weights to the criteria and the stations. This will be used for computation of overall weights for the stations with respect to the criteria. The higher weight stations will be retained as selected stations using a threshold. The decision criteria for locating carsharing stations were obtained by literature review on car sharing, discussion with carsharing experts and on-hand experience with LISELEC carsharing system in La Rochelle. These criteria are the population density, the parking difficulty and cost, the combination of land use – habitation, employment, commerce and local amenities, the presence of target groups, the transit/multimodal access by transport, and finally the vehicle ownership. The proposed methodology was applied to an urban community of La Rochelle. Three locations were selected for pursuing the carsharing study. These three locations were rated by different experts using the 6 criteria. In the second stage, different criteria and stations are weighted using pairwise comparison. After the individual weightings for the criteria and the stations are obtained, the overall weightings of the stations for all the criteria is computed. In the third stage, the higher weight stations from the rest is selected using a threshold. All those stations whose overall weight exceeds the threshold limit will be considered as final stations for carsharing implementation.

In another study by El-Fassi, Awasthi, and Viviani (2012), a discrete event simulation-based decision support tool that assists the decision makers in selecting best network growth strategies is presented. This tool allows any CSO to model a given set of stations, where a growth potential has been preliminarily identified, and test different growth strategies to effectively satisfy the demand. The growth potential of the network is identified systematically by applying four steps: (i) network segmentation, (ii) network region selection, (iii) member's segmentation, and (iv) growth factor selection. Then different network growth scenarios such as increasing the capacity of existing stations, merging of stations, implementing new station, or a combination of all scenarios are simulated using a discrete event model to obtain a scenario performance index. The scenario performance index is defined as the weighted sum of various system performance metrics of stations activity, members activity, and members satisfaction level. A case study of Communauto Inc. operating in Montreal, Canada is presented and the best strategy of expanding the service network is find out as decreasing the capacity of one of the existing stations and building a new station in the potential growth region.

Correia and Antunes (2012) presented a mixed-integer programming model to maximize the profit of CSO considering all revenues and costs by optimizing the number, size, and location of stations. Therefore, vehicle relocation is not considered as a way to increase demand satisfaction. The system makes

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revenue from the trips paid by clients and pays the costs as total of the vehicle maintenance costs, the vehicle relocation costs, the station maintenance costs, and the vehicle depreciation costs. Three schemes of operation of carsharing system has been considered and corresponding MIP models are presented: (i) Controlled Service as the CSO has total control over the selection of trips from a list of requests, (ii) Full Service as the CSO will accept all requested trips, (iii) Conditional Service as the CSO can only reject the requests if there are no vehicles available at the pick-up station. The MIP models are solved using branch-and-cut algorithms for the case study on data from Lisbon, Portugal and the results of three model schemes are compared.

Lopes, Martinez, and Correia (2014) used agent-based simulation to model the station-based one-way carsharing systems in detail in order to assess its potential economic performance from the users' perspective and the carsharing operator. A discrete time and space stochastic model based on Poisson distribution is used to simulate the demand and detailed road network for the city of Lisbon, Portugal is incorporated. Based on the road network of Lisbon, an optimization model adopted from the p-median formulation is developed to estimate the location and relative dimension of the stations. The capacity of each station is calculated by distribution of given total number of the parking stations according to the station's relative dimension. The network operator and customers are the agents which control the car fleet and the staff reactive agents. They ran the simulation and concluded that the uneven distribution of the demand can be studied by having a large fleet for the peak-hours, but it leads to higher costs and a low occupancy rate through the day. The uneven distribution of trips in time and space creating severe dissatisfaction due to unsatisfied demand. Finally, a ratio of two parking spaces per car results better equilibrium between costs and satisfaction.

Hu and Liu (2016) focused on the joint design of stations capacity and optimal number of vehicles for one-way station-based carsharing system. The network of servicing vehicles, stations and connecting routes between the stations is considered as a closed queuing network because vehicle arrival process at the stations and the routes is depending on the departure process (i.e. vehicles never leaving the network). The user arrival process at any station is independent of the user departure process. Therefore, the users and the stations form open queuing networks. As result, the entire carsharing system is a mixed queuing network of one closed queuing network and N open queuing networks where N is the number of stations. A successful trip is modeled as three queues:

1. $M/M/n_i/n_i$ user queue with an independent arrival of user and n_i available vehicles as parallel servers. The arrival and service (i.e. time interval between the reservation time and departure time) process are considered as homogeneous Poisson and exponential distribution processes respectively and n_i is a random variable.
2. $M/M(n_{ij})/1/C_{ij}$ vehicle queue is the model of each route with n_{ij} vehicles and the remaining capacity C_{ij}. The arrival rate corresponds to the time interval between two consecutive arrivals at each route and depends on the total fleet size. The remaining capacity C_{ij} is the maximum number of shared vehicles that each route can hold according to the number of non-shared vehicle on the road and given as input.
3. $M/M(n_i)/1/C_i$ station queue with fleet-dependent vehicle arrival rate, state-dependent service rate, single server, and virtual storage to model arrival of the vehicles to the stations. When there is no parking available, vehicle cannot have returned and needs to wait at the virtual storage. The mixed queuing network is solved with different level of computational complexities.

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The small network of less than 10 stations is solved by and extended Mean Value Analysis (MVA) algorithm and the medium-sized network of 11 to 50 stations is solved by an extended Schweitze-Brad MVA (SB-MVA) algorithm. The large size carsharing systems of more than 50 stations are simplified by merging the routes connected to the same destination station and then solved with SB-MVA algorithm. A non-convex integer programming model is defined to maximize revenue of the system with the optimum number of vehicles of the system and capacity of the stations. The algorithms for solving queuing network are nested into the optimization framework. To solve the optimization-model a genetic algorithm is proposed. The method experimented on four different cases:

1. small network, three-station example with low demand based on real collected data in Singapore,
2. small network, three-station example with high demand,
3. medium size, 49-station example, and finally
4. large size, 100-station example.

The results show that without considering the booking process or the road congestion, the optimization model will generate non-realistic solution and overestimate the profit, given different level of existing road congestion, the profit is maximized when the road congestion is moderate, and the smaller booking to pick-up time interval will greater the optimal design with lower parking capacities and lower fleet size.

Huang, Correia, and An (2018) presented a Mixed-integer Non-linear Programming (MINLP) model of one-way station-based carsharing system to jointly optimize the station location, station capacity and fleet with vehicle relocations. the demand is considered dynamic and asymmetric where the requests to travel between traffic zones fluctuates along the day and is not symmetrically distributed in space. It is also assumed that the demand of is known in advance through an on-line booking system or by prediction through historical data. The operator is considered to relocate the fleet at the end of the operation period in order to rebalance the vehicle inventory back to its initial level thus, it the operator is allowed to accept or reject the requests subject to vehicle availability. The model is set to find station location, stations' capacity, and fleet size in order to maximize the profit of the system. A gradient procedure by using the notion of service attractiveness is developed to solve such a large-scale MINLP problem. For a demonstration of the application of the model, the Suzhou Industrial Park in Suzhou, China is used as the case study region. The solution of the optimization problem resulted from commercial solver

Table 2. Summary of carsharing location planning and stations capacity research

Reference	System Type	Modeling Technique
(Boussier et al., 2005)	Station-Based	Fuzzy modelling
(Cheu et al., 2006)	Station-Based	Multi-Layer Perceptron Neural Network Support Vector Machine
(Awasthi et al., 2008)	Station-Based	Analytical Hierarchy Process
(Awasthi et al., 2012)	Station-Based	Discrete Event Simulation
(Correia & Antunes, 2012)	Station-Based	Mixed-Integer Programming
(Lopes et al., 2014)	Station-Based	Agent-based Simulation
(Hu & Liu, 2016)	Station-Based	Mixed-Queuing Network Model
(Huang et al., 2018)	Station-Based	Mixed-Integer Nonlinear Programming

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MINOS in AMPL Education Version 12.2 as well as self-developed program using Gurobi 7.0.2 solver in Python is obtained and compared regarding computation efficiency. Results show that the objective value is increased by 46.56% while the computation time is increased by 645.07% using the proposed gradient procedure solution. Finally, a sensitivity analysis with respect to the cost component, on the market share, total profit, and the relocation operations is conducted and it is found out that pricing is the key issue that affects the carsharing system performance.

Fleet Relocation and Station Rebalancing

The most important problem of one-way carsharing systems from operational point of view is to ensure availability of enough cars in stations to serve the users. This problem is an intrinsic property of the one-way carsharing systems and arises from the nature of this kind of service. Many researches have tried to address this problem. The literature can be categorized into three general solutions:

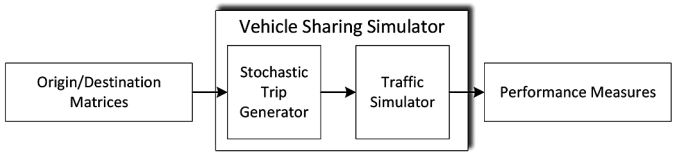
1. Implementing policies, methods and incentives for the users of the system in a way to avoid the system to be imbalance.
2. Providing a fleet of trucks and staffs to relocate the cars between the stations in order to balance the system after or before operating hour of the service. These methods are called static because the state of the system is not changing over the course of rebalancing operation.

Providing a fleet of trucks and staffs to relocate the cars between the stations in order to balance the system in fixed time intervals or at certain time that the system become imbalance during operation hours of the service. These methods are called dynamic because the state of the system may change during rebalancing operation.

Relocation by Users

Barth, Todd, and Xue (2004) introduced two user-based relocation mechanisms: trip joining and trip splitting. The number of available vehicles cars in the stations comparing the number of reservation demands registered on the system or based the historical analysis of the demands the system could realize that it is becoming imbalanced. The users traveling to destination stations which more vehicles are needed and that have more than one passenger are asked to take separate (trip splitting). If two users are at the origin station at the same time traveling to the same destination, the system can ask them to rideshare (trip joining). Applying new methods of pricing motivates the users to accept the trip joining or splitting suggestions of the system. A multiple-station vehicle sharing system simulator has devolved using a queuing-based, discrete event model. The simulator input is estimated travel demand data and

Figure 2. Building blocks of queuing-based, discrete event vehicle sharing simulator



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the output is the overall performance of the system in terms of vehicle balance, vehicle availability, efficiency, and the number of required relocations.

The simulator is calibrated by real-word data of IntelliShare vehicle sharing system implemented on and near the University of California-Riverside (UCR) campus since April 1999. This system uses a fleet of 35 electric vehicles on 5 stations. The membership is open to UCR faculty, staff and students. The simulation performed under the assumption of complete cooperation of the users on four scenarios: staff relocation, trip joining, trip splitting, and both trip joining and splitting. The results show the overall number of required relocations drop 11% by employing ride sharing policy, 26% by employing ride sharing policy, and 42% by employing ride sharing policy comparing to the relocations (Barth et al., 2004). The effect of imposing the suggested relocation policies on other performance measures such as vehicle balance, vehicle availability and system efficiency has not shown in this study.

Febbraro, Sacco, and Saeednia (2012) studied the one-way vehicle sharing system by discrete event simulation method. The number of reservations in the provided model is directly associated with the vehicles, instead of the stations. The demand or reservation events are assumed to be Poisson process; the users are allowed to modify or cancel their reservations. A user-based relocation strategy is applied. Optimal positions for returning the vehicles are determined and transferred to users. Users can accept or refuse the suggested drop-off station, but a pricing incentive is given to the users to motivate them accepting the proposed destination. The system tries to minimize unsatisfied demands by providing certain number of available vehicles in each station. The non-linear optimization problem solved by reformulating it as linear integer programming problem. The model evaluated by testing the system on a traditional carsharing system in Turin.

Waserhole and Jost (2013) considered a real-time station-to-station protocol where users ask for a vehicle at a specific pick-up and drop-off station. The system offers a price which user can accept and book the car or refuse and leave the system. A continuous-time Markov chain model is proposed to compare the performance of proposed pricing policies. An algorithm based on the Maximum Circulation problem is studied to approximating the policy which is maximizing the transit.

Static Relocation

A qualitative analysis conducted by Kek, Cheu, Meng, and Fung (2009) on operator-based relocation systems provides insights on the key issues involved and their influences over each other. Based on this analysis, a time-stepping novel three-phase optimization-trend-simulation (OTS) model is developed, and three performance indicators are proposed to evaluate the effectiveness of the different relocation techniques. Phase one of the OTS is an Optimizer, which receives inputs from the carsharing system on its stations' characteristics such as the number of parking stalls, inter-station vehicle relocation costs, staff costs, penalties for low level of service (LOS) for customers, typical or historical customer usage patterns and vehicle maintenance schedules. The Optimizer then proceeds to determine the lowest-cost resource allocation, giving the optimized staff strength, staff activities, relocations and the resulting station status (number of vehicles at the stations at each time step). The availability of staff who perform operator-based vehicle relocations and maintenance activities can be arbitrarily set in phase one and later revised through a series of heuristics in phase two. In phase two, the Trend Filter receives the optimized outputs from phase one and filters them through a series of heuristics. A set of recommended operating parameters (staff strength and shift hours, relocation technique, relocation thresholds and whether priority should be given to maintenance jobs or relocations) is thus obtained. Upon entering the set of

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operating parameters obtained in phase two into the vehicle relocation simulator, phase three of the OTS evaluates the effectiveness of this set of recommended parameters using three performance indicators:

1. duration of vehicle shortage,
2. duration of parking stall unavailability, and
3. number of relocations.

For the optimal performance of the system, the values of these indicators should all be zero. The objective of the optimization problem is to allocate staff resource and staff activities to minimize the generalized cost associated with the vehicle relocation activities. The generalized cost includes staff cost, vehicle relocation cost and penalty cost for low level of service which is reflected by the duration of vehicle shortage and duration of parking stall unavailability. The mixed integer programming formulation for this problem is provided and the branch-and-bound technique is suggested for solving the model. The OTS system has been tested and validated on real data provided by Honda ICVS.

Wang, Cheu, and Lee (2010) proposed a model consisting of three main components, i.e., microscopic traffic simulation, focus forecasting and inventory replenishing to forecast and relocate vehicle resource for carsharing services. A customized microscopic simulation model was adopted to model real-street-network traffic conditions. An actual suburban network of the Clementi area of Singapore was used for the simulations conducted in this study. A program was developed to collect the travel time of each link along the Clementi network through traffic simulations. A link-to-link shortest path algorithm with turn penalties was embedded into the program to search for the shortest time paths for each origin-destination pair. In this study, several time series techniques such as selective moving averages, Holt's model, Winter's model as well as Tabu-Search heuristics were deployed and compared. For each time period, multiple forecasts are generated. Focus forecasting then applies the forecast using the technique that would have been the most accurate if it were used for the most recent historical time period. The forecasted demands were then fed into the following inventory-replenishing model. For each inventory decision of vehicle stocks, major considerations are reviewed, and guidelines are developed. The decisions include vehicle inventory tracking, determining when to replenish inventory, and determining the amount to replenish. Once the relocating decision is made, the under-stocked station will be replenished from the nearest overstocked station in terms of the lowest travel cost at that moment of reallocating (the shortest lead time for the requested products), which was determined by the microscopic traffic simulation model.

Benchimol et al. (2011) modeled the static rebalancing problem as CTSP-PD and named it "1-commodity swapping problem with capacity" and addressed it from a theoretical point of view, proved the problem is NP-hard from the complexity point of view, and then provided a 9.5-approximation algorithm. A 2-approximation algorithm is described for the case the network is a complete graph with unit costs. Finally, they proved that the problem is polynomial when the graph is a tree.

Erdoğan, Battarra, and Calvo (2015) presented the mathematical definition or the Static Vehicle Rebalancing Problem aimed to determine the minimum cost sequence of stations to be visited by a single truck that relocating the vehicles among the network in order to balance the network. Multiple visits to a station are allowed, as well as using a temporary depot station. This temporary depot station could be an initially balanced station that visited in order to temporary park the vehicles during the relocating process. The fuel consumption, travel time, and CO_2 emission is modeled in the cost function. The Authors adopted time-indexed formulation defined in (Chemla, Meunier, & Calvo, 2013) and applied a separation algorithm for combinatorial Benders' cuts . The algorithm is based on two observations:

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any solutions is corresponding to a Eulerian circuit starting and ending at the depot and the Eulerian circuit can be represented as a time-indexed network where the time dimension of the vertices is defined by the order they are visited. This separation algorithm performs well for near-optimal solutions but may perform poorly for low quality solutions. To avoid the latter case, a greedy constructive heuristic is prioritizing the exhausting imbalance stations. Finally, the algorithm was computationally tested to solve two instances sets with up to 60 stations and the results compared to (Chemla et al., 2013) from the optimality and CPU time point of view.

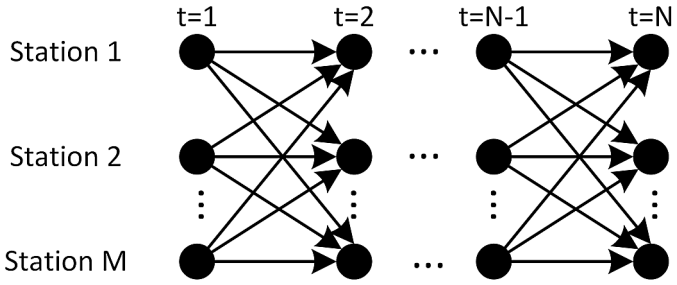
Dynamic Relocation

Mukai and Watanabe (2005) suggested a dynamic relocation algorithm in which a control center issues relocating requests to location controllers by watching positions of cars with a global positioning system. A candidate car for relocating is selected based on virtual spring forces. The virtual springs is attached to two places of each vehicle: between the car and other cars and between the car and borderlines of a service area. High movement energy of a car which is depending on the above virtual spring forces, shows the off-balance of car distribution. The relocation algorithm finds the car with the maximum movement energy and station with minimum energy and then send a relocating command to location controller who is closest to the car to move the maximum energy car to the minimum energy station. This algorithm generates relocation command only when the system receive a demand from the user and there is no car available in the station to serve the demand.

Fan, Machemehl, and Lownes (2008) formulated the Dynamic Vehicle Allocation Problem for Carsharing (DVAPC) and solved it under a finite planning horizon. DVAPC is stated as deciding on acceptance or refusal of users' demand request for vehicle reservation at any time as well as number of vehicles to relocate between the stations in order to achieve higher level of user satisfaction in future. In other word, the objective is to maximize the total expected profits over a predefined period of N days. The Network flow of DVAPC represented as a spatiotemporal graph as shown in Figure 3. To simplify the problem for formulation, travel time between the stations uniformly given equal to 1 day, all demands in a day given known at the beginning of that day, and the demands of all pairs of stations conformed to a discrete (such as Poisson) or continuous (such as Normal) distribution with known parameters.

The DVAPC with finite time periods can be transformed to a multi-stage stochastic linear programming problem with recourse. The objective of the N-stage stochastic linear programming problem is to maximize total profits over the N time period horizon. The revenue for satisfying a carsharing demand between two stations as well as the cost of relocating the between stations are given constant over time

Figure 3. Network flow representation of Dynamic Vehicle Allocation Problem for carsharing



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in the model. The Monte-Carlo sampling-based method is used as the solution methodology to compute a feasible solution within a certain percentage confidence. Finally, a small network of four stations in a time period of 5 days has solved by the suggested method (Fan et al., 2008).

Nair and Miller-Hooks (2011) formulated the problem considering demand uncertainty. The demand is anticipated in short-term and the operators initiate to rebalance the network by fleet redistribution. The model is also generating partial redistribution plans when operators have insufficient resources to meet demand. Two solution methods are presented: the first approach deals with the problem when demand at stations is correlated, and the second solution method is developed when the demand at each station is assumed to be independent. They focused on the level-of-service constraint defined as the proportion of satisfied demands while minimizing the cost of relocation of vehicles across the network. The demand process is assumed to be Poisson distribution and the demand-supply interaction is ignored to simplify the problem. Rebalancing the network is considered four times in each day and the model applied to The Intelligent Community Vehicle System (ICVS) operated by the Honda Motor Company in Singapore City, Singapore. Nine strategies for rebalancing are tested. The strategies are based on expected value, doing nothing, the enumeration-based solution method, the cone-generation method, and the failure apportionment bound, and the simulations ran for different proportion value of satisfied demands. In simulation studies, the cone-generation method strategy demonstrated robustness over all sampled demand scenarios.

Fan (2013) developed a stochastic optimization framework to address the dynamic vehicle allocation problem for carsharing systems. The service operator determines the optimal vehicle allocation in both time and space to maximize the profits. This study discussed the possibility of considering the dynamic and stochastic properties of the system simultaneously. The final objective is to maximize the total expected profits based on independent random future demands with a known distribution over a specific period of time. A station-based on-way carsharing system with prior reservation is assumed. A multistage stochastic linear integer model with recourse is formulated. A scenario tree has been set up with the carsharing demands for all origin–destination pairs and the first-stage decision are obtained by solving the problem using the exact stochastic optimization method. The computation efficiency and solution quality are discussed and a numerical example of four station with seven-stage network is solved.

Pfrommer, Warrington, Schildbach, and Morari (2014) presented a vehicle sharing system where periodic relocating of vehicle among the stations is done by using several trucks. They also considered an incentive policy through a pricing scheme to the users to leave their vehicles to a station different from what they originally intended. The user demand statistics obtained from historic data of the bike sharing system. Then, for a fixed planning horizon, truck routes for optimal redistribution of vehicles across the stations are determined. The problem formulated the benefit of removing or adding vehicles at the station at the current time with respect to the increase of satisfied user's percentage at this station in the near future as a form of a utility function. The flows of the vehicles in the network is assumed deterministic. Then, the best route is founded for the case when only one truck is used. To solve the problem of finding the best routes the authors assumed that during each trip, the single truck can visit at most a small constant number of stations. Then, they use a greedy approach and they build a tree rooted from a specific station named depot. A few stations are added iteratively to the tree so that the increase in the utility function over the additional cost is relatively high. After constructing the tree, a separate optimization problem is solved for each different route starting from the root of the tree and ending at the tree branches (Figure 4).

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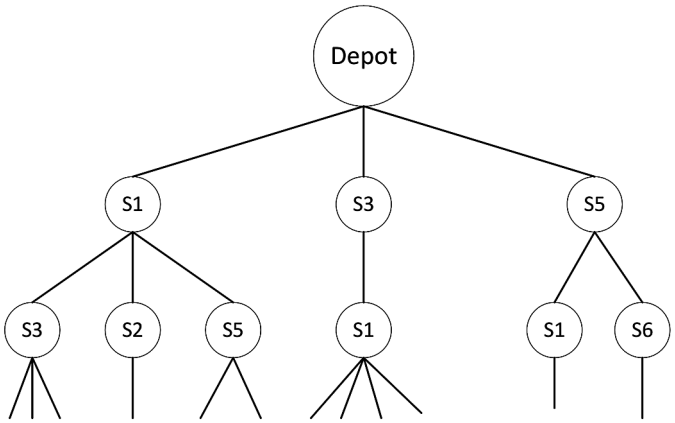
Figure 4. Tree representation of the network of the stations for finding the best relocation routes



Carlier, Munier-Kordon, and Klaudel (2015) considered a station-based one-way carsharing system and tried to provide solutions for the optimization problem consists in maximizing the total number of satisfied demands for a limited number of vehicles and relocation operations where the set of demands at each station assumed to be known and fixed. Three objectives considered for the optimization problem: (i) Maximizing the total number of satisfied demands, (ii) Minimizing the total number of vehicles, and (iii) Minimizing the number of required relocations. The problem is modeld as an Integer Linear Program (ILP) using a time expanded directional graph of the stations over time. Lastly, the optimization problem is solved for an experimental condition with the instance size of 50 stations, some strategies discussed for reducing the graph density and improving the solving time. It is concoluded that the increasing the relocation frequency has a few impacts on the total number of satisfied demands and a good level of service could achive by scheduling the relocation operation every two hours for the experimental instance.

Santos and Correia (2015) designed a Mixed Integer Programming (MIP) model that uses a rolling horizon to reduce the uncertainty of the demand and ease the number of decision variables of the model for a station-based one-way carsharing system. A rolling horizon involves making the most immediate decisions based on information and forecasts that look further into the future by considering the entire planning horizon. The entire operation time is divided into a series of planning horizons which has a fixed and a changeable part. The MIP model is based on the model provided by (Kek et al., 2009) but is improved to be used in rolling horizon planning approach. In the new model the trip joining of staff is also allowed to reduce costs. The demand is assumed to be known before optimization process started. The objective function minimizes the total cost of the operation including the cost of staff rebalancing operations and vehicle relocations, the cost of rejected demand, and a penalty for maintenance requests not fulfilled. The model was tested using the optimization software Xpress-MP. Various instances of the problem with randomly generated demands are tested and the computation times for solving the optimization functions are obtained. The results show that dividing the operation period into smaller planning periods allows application of the proposed model for real time instances based on a rolling horizon planning approach.

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Table 3. Summary of fleet relocation and station rebalancing research

Reference	System Type	Relocation Policy	Objective Function	Solution Methodology
(Barth et al., 2004)	Station-Based	Users-based	Minimize number of relocations	Non-linear pricing
(Febbraro et al., 2012)	Free-Float	Users-based	Minimize rejection ratio	Price incentive
(Waserhole & Jost, 2013)	Station-Based	Users-based	Maximize number of taken trips	Dynamic pricing
(Kek et al., 2009)	Station-Based	Static	Optimize man-power and operating parameters	Mixed-integer programming
(Wang et al., 2010)	Station-Based	Static	Maximize number of served demand over total number of demands	Stock Replenishment
(Benchimol et al., 2011)	Station-Based	Static	Minimize relocation truck route	1-commodity swapping with capacity
(Erdoğan et al., 2015)	Station-Based	Static	Minimize relocation cost	Mixed-integer programming
(Mukai & Watanabe, 2005)	Station-Based	Dynamic	Maximize utilization rate	Virtual spring force
(Fan et al., 2008)	Station-Based	Dynamic	Maximize profit	Multi-stage stochastic linear integer
(Nair & Miller-Hooks, 2011)	Station-Based	Dynamic	Minimize relocation cost in order to satisfy near-future demand	Stochastics Mixed-Integer Programming (MIP)
(Fan, 2013)	Station-Based	Dynamic	Maximize profit	Multistage stochastic linear integer model with recourse
(Pfrommer et al., 2014)	Station-Based	Dynamic	Minimize operating cost for a given desired service level	Model-based predictive control
(Carlier et al., 2015)	Station-Based	Dynamic	Maximizing satisfied demand and Minimizing number of vehicles and required relocations	Integer Linear Programming
(Santos et al., 2015)	Station-Based	Dynamic	Minimizing total costs	Mixed Integer Programming (MIP) model with a rolling horizon

Charging Network for EV Carsharing Systems

Environmental and economic advantages of electrical cars made them a good candidate to be used in the carsharing systems. This leads to potential need for a comprehensive design framework for an EV carsharing system. There are high exceptions of integrating EVs and carsharing systems. But a high performance, economically feasible deployment of an EV sharing systems needs a comprehensive design framework (Winter, Cats, Correia, & Arem, 2016).

Correia and Santos (2014) presented a Mixed Integer Programming (MIP) model for satisfying all demands by optimal trip assignment of electric and conventional vehicles while maximizing the number of trips with EVs and the generated profit. A case study of the problem based on the data from Portugal central region is solved using branch-and-cut techniques provided in the FICO Xpress 7.5 software package and the results are discussed.

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Li, Ma, Cui, Ghiasi, and Zhou (2016) proposed a carsharing system design framework that considered both planning of station location and fleet size and dynamic rebalancing of the EVs. A continuum approximation (CA) model for determining the optimal configuration of stations and allocated number of cars to each station is proposed. The total system life-time cost is minimized while maintaining the service reliability. In the model, station construct investment, vehicle maintenance, transportation and vehicle rebalancing are considered as the system life-time costs. The model is decomposed into small neighborhood that each can be approximated by an infinite homogeneous plane (IHP). The system cost of an IHP is a unimodal function of the facility service area size which can be solved in a sub-linear time by bisection algorithm. The CA solution is approximated by integrating of all IHP solutions. The proposed framework is assumed (1) the trip rate is dense and time and location independent, (2) charging capacity is always greater that fleet size so there is no waiting time for EVs to be charged, (3) only fully charged EVs available to the users, (4) the EVs speed are always constant and they are not influenced by traffic congestions, and (5) the relocating cost of an EV is fixed regardless of the moving distance.

Electric car sharing will not only be very impactful on the urban transportation system but also on the planning and management of the power grid. Specifically, the travel patterns of an electric shared vehicle are significantly different from that of a privately owned EV. Private cars are highly under-utilized and stay parked most of the time, which facilitates the control of the charging process. On the contrary, rental periods of shared vehicles are typically short, thus charging requests are frequent and batteries should be rapidly recharged.

Biondi, Boldrini, and Bruno (2016) has studied the energy demands of a car sharing system under various deployment scenarios. The effectiveness of the deployment model has assessed by adopting a data-driven evaluation methodology that uses the travel patterns of a large-scale free-floating carsharing system as data sources. The demand is estimated based on all the pickup and drop-off events of electric shared vehicles for a free-floating car sharing service provider operating in The Netherlands. Then, the same demand patterns would occur in an equivalent station-based system deployed in same area has assumed. The urban area in which the car sharing infrastructure should be deployed is partitioned into a set of non-overlapping square cells and a potential station is deployed at each cell. The travel demands associated to the potential station has modelled as two stochastic processes: (a) The drop-off events and (b) The Pick-up events. Both events in the coverage area of the station has modelled as a Poisson processes. The parking availability stochastically modelled as $M/M/1/k$ by adopting a queueing theoretical approach. Finally, the stochastic optimization problem has formulated to minimize the deployment cost of the infrastructure. A greedy search algorithm provided near-optimal solutions. The results show power sharing technologies can be used without negatively affecting the state-of-charge of departing vehicles and ensuring a significant reduction in infrastructure investments.

Boyacı, Zografos, and Geroliminis (2017) developed a discrete event simulation-optimization framework to optimize operational decisions for vehicle and personnel relocation in a reservation-based electric carsharing system. A multi-objective mixed integer linear programming problem (MMILP) with hierarchical objective functions is proposed. The objectives are to maximize the satisfied demand and to minimize the relocation cost. The demand is prioritized over relocation cost and profit. In order to decrease the number of variables in the simulation-optimization model, stations are clustered using a k-Medoid algorithm approach and forced charging strategy is selected. The latter restrict the EVs to fully charged after each trip. The simulation-optimization model was implemented in in C# .NET environment and IBM ILOG Cplex Version 12.6 with Concert Technology was used for solving MILPs. A case study

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using the data from VENAP Auto Bleue round-trip CSO of Nice, France is studied and the performance measures for runs with different demand levels and configurations is discussed.

Brendel, Lichtenberg, Brauer, Nastjuk, and Kolbe (2018) presented a discrete event simulation framework consisting of four modules for automated optimization of operational decisions regarding the usage of EVs in mixed vehicle-type carsharing systems. The modules are energy demand prediction, battery charge scheduling, vehicle selection, and vehicle relocation. The energy prediction module uses energy demand value within the given test data as perfect prediction method and an estimation of the energy demand based on average energy demand using historic rental data as a worse prediction method. The charging module utilizes two approaches for charging strategy: (i) threshold approach which using a threshold for state of charge to determine if the EV should be charged or not and (ii) continuous charging approach were EVs charged irrespective of their current state of charge. The selection module determines if an EV or a conventional car must serve a demand the module is designed in a way to prioritize EVs over conventional vehicles. The relocation module follows the user-based relocation framework of previous research by the authors. Finally, the results of three different scenarios of carsharing without EVs, carsharing with only user-based relocation, and carsharing with EVs are provided and discussed.

Self-Driving Carsharing System

The automated vehicle, which once was only dreamt of by futurists, is now rapidly developing. Many research groups all over the world are working and competing on self-driving car development and the first prototypes are starting to roll out from design to reality. There are natural synergies between shared autonomous vehicle (AV) fleets and electric vehicle (EV) technology, since fleets of AVs resolve the practical limitations of today's non-autonomous EVs, including traveler range anxiety, access to charging infrastructure, and charging time management. In this section we survey the literature on the automated carsharing system.

Spieser et al. (2014) investigated the fleet sizing problem for autonomous carsharing system which aims to replace passenger vehicles currently service the entire population of an urban area. They modeled demands according to a non-stationary spatio-temporal Poisson process and tried to solve two problems: (i) finding the minimum number of vehicles necessary to keep the number of outstanding demands, and (ii) finding the number of vehicles required to guarantee a certain level of the quality of the service. Therefore, they used the "Taxi Data", "Road Network", and "Household Interview Travel Survey" datasets of Singapore to apply their analytical results to estimate fleet size for a real-world scenario. Finally, the total mobility cost for users in two competing transportation models of human-driven cars versus shared self-driving cars is studied. The total mobility cost is defined to be the sum of explicit costs such as purchase, service, park, insurance, and fuel costs and hidden costs such as time spent taking a car to get tune-up, renewing license plates, and driving the car. In conclusion, they found it is much more affordable to access mobility in an autonomous carsharing system compared to traditional mobility models based on private vehicle ownership.

Fagnant, Kockelman, and Bansal (2015) presented an agent-based simulation model to investigate the potential implications of the shared autonomous vehicles. This investigation examines the implications by modeling Austin, Texas. A population of one-way trips was generated from the region's zone-based trip tables as the travel demand. The simulation model consists of four primary submodules: location and trip assignment, fleet generation, movement, and relocation. The location module operates by determining which available vehicle are closest to waiting travelers and then assigning it to those trips. The

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fleet generation is generating new vehicle when any traveler has waited for 10 min and is still unable to locate an available vehicle. This module is used to determine the optimum fleet size. The movement module is responsible to simulate the traveling on the network and tracking the position of the vehicle on the shortest-path route which is previously computed. The relocation module relocates the vehicles in response to waiting travelers and the anticipation of next 5-min demand in order to reduce the total amount of unoccupied vehicles. Four relocation strategy has been simulated and the results were compared. Finally, the electric vehicle use implications and emission implications are discussed.

Chen, Kockelman, and Hanna (2016) studied the management of a fleet of shared autonomous electric vehicles using an agent-based model. Operation of the system under various vehicle range and charging infrastructure scenarios is simulated and a case study on Austin, Texas has been done. The city is modeled into a square 100-mile by 100-mile gridded metropolitan area, divided into 160,000 quarter-mile by quarter-mile cells and divided into four zones based on the population density pattern of Austin. The demand is generated using a non-stationary Poisson distribution with average rate for each 5-min time step within a 24-h temporal distribution following the 2009 National Household Travel Survey. Two passes of simulation is considered: warm start and full run. In the warm start phase, it is assumed that there are enough vehicles to address the demand, then charging stations are added to the model to satisfy the charging demand of the fleet. Then number of required charging stations and their locations determined when the warm start phase of the simulation reaches a steady-state condition. Similarly, in the free run phase, it is assumed that the charging stations and their locations are fixed from the warm start phase and the model tries to find the number of required autonomous vehicles to serve the demand and reduce the waiting time to a certain level. Five different scenarios for different type of vehicles and charging stations is created and simulated for a period of 50 consecutive days.15 performance indices such as average daily miles per vehicle and average wait time per trip are defined as the output of the simulation model and the results are compared.

Correia and Arem (2016) studied the impacts of replacing privately owned conventional vehicles with automated ones on urban mobility. A Mixed Integer Programming model is formulated to minimize the total transport cost of all households in the city by assuming that trips performed by the household members are either satisfied by the AVs or by public transport. The MIP is solved using a branch-and-bound algorithm implemented in the Mosel language and solved using FICO Xpress 7.7. The model applied to a small network in order to validate the model and then applied to the case study network of Delft, Netherlands. Several policy and future uncertainty scenarios are described, and their results are discussed. The authors concluded concluded that the AVs can satisfy more trips than the conventional vehicles and create only a small increase in congestion despite the extra kilometers.

DISCUSSION

The survey of the research literature about design, implementation and operation of carsharing systems shows the complexity of the problem. Although research from different perspectives has been done, the problem still needs more analysis and solutions. Issues and challenges of the system at every level from strategic design to operational management are inter-related and directly affect the success of the system.

Demand modeling is fundamental for designing an economically feasible carsharing system and a key factor for developing efficient and effective policies and procedures in operation of the system. The research on this problem are very few and all the proposed models are only validated for specific cities.

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There is no generally validated model to estimate demands for the service based on location of the stations and time quantitatively.

Most of the literature has addressed the problem of rebalancing raised from the very nature of the system. The simplest policy is providing an incentive for the users to move the vehicles between the stations in order to satisfy more demands. But, the lesser flexibility and easiness for users will reduce the success of implementing these policies. Therefore, this type of policies is not used by carsharing organizations today. The static relocating of the vehicles across the network in pre-determined time periods, neglecting the system dynamics at the time of rebalancing, is well studied in the literature. There are many approaches and solution for the problem defined and analyzed. However, to simplify the problem every research team made their own assumptions and defined specific objective function and decision variables. This makes the comparison of the efficiency of the solutions difficult. Similarly, the dynamic relocation solutions are also based on different assumptions and simplifications. There are very few articles that addressed the problem considering the prediction of the near-future demands dynamically. The free-float one-way carsharing systems are totally forgot in the literature. There are only few articles addressed the issues of such systems.

The one-way carsharing systems become more complicated for the electrical vehicle fleets. EV-based carsharing systems need extra attention to the problem of charging the batteries. Charging policy of the fleet, distribution of charging stations and the required infrastructure are add-on complexities of such systems.

The study on the autonomous carsharing systems is on its early stages. Despite the very first research and studies on the issues such as fleet sizing. The need for a comprehensive design framework and operation model of such car-as-service systems are yet to be discussed.

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KEY TERMS AND DEFINITIONS

Carsharing: A short-term vehicle access among a group of members who share a vehicle fleet that is owned by a third-party organization.

Carsharing Organization: An organization that own, maintain, manage, and insure a fleet of vehicles in order to provide carsharing service.

Dynamic Relocation: The fleet relocation which is done during the service hours of the carsharing organization while the demands are responded, and the state of the system may change during the operation.

Fleet Relocation: Relocation of the vehicles between the stations or among pre-defined zone of the city in order to balance the system.

Free-Float: A Carsharing system which the pick-up and drop-off of the vehicle is possible freely in a defined zone of a city, as vehicles have no fixed positioning.

Staff Rebalancing: The transportation of staff members of carsharing organization between the stations in order to perform a vehicle relocation.

Static Relocation: The fleet relocation which is done before or after the service hours of carsharing organization when the state of the system is static, and no demand responded within the operation.

Station-Based: A carsharing system which has fixed location for vehicle pick-up and drop-off.

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Chapter 19
A TQM-Based Multi-Dimensional Approach to Improve the Quality of Supplier Selection in the Retail Industry

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ABSTRACT

In this chapter, the authors study risks in supply chain management, in the process of supplier selection for the procurement department of a retail supply chain. They propose a TQM-based multi-dimensional approach to improve supplier quality. They discover how the potential risks influence the performance of procurement in the supplier selection process of supplier relationship management. This chapter introduces a current supplier assessment approach by using weighted score ranking method as a single dimension mechanism for supplier selection in a specific retail industry. To estimate the efficiency of this mechanism, they use principal component analysis (PCA) statistical approach on real datasets to identify the most important factors that influence the decision-making of supplier selection. The strengths and weaknesses of this single dimension weighted ranking method are analyzed. The authors propose a total quality management (TQM)-based multi-dimensional mechanism to help the buyer identify, avoid, monitor, and reduce potential risks instead of using linear weighted score ranking method.

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1. INTRODUCTION

In the past several years, the topic of supply chain risk management has been researched and discussed in the inner circles of operations professionals, business management references etc. According to definition of SCOR risk management mode, "Supply chain risk management is the systematic identification, assessment, and quantification of potential supply chain disruptions with the objective to control exposure to risk or to reduce its negative impact on supply chain performance (SCOR, 2007)." In SCOR 8.0 mode, it is said that "Potential disruptions can either occur within the supply chain (e.g. insufficient quality, unreliable suppliers, machine break-down, uncertain demand etc.) or outside the supply chain (e.g. flooding, terrorism, labor strikes, natural disasters, large variability in demand etc.)." Also, "Management of risk includes the development of continuous strategies designed to control, mitigate, reduce or eliminate risk." Therefore, contents of SCOR risk management model include identifying risk, designing detection measures, controlling risks exposure, eliminating risks etc. In the literature of Wagner and Bode (2006), it is easy to distinguish such terms:

- *Supply chain risk*: It is defined as the negative deviation from the expected value of a certain performance measure, resulting in negative consequences for the focal firm. Hence, risks are equated with the detriments of a supply chain disruption.
- *Supply chain disruption*: A supply chain disruption is an unintended, untoward situation that leads to supply chain risk. For the affected firms, it is an exceptional and anomalous situation in comparison to every-day business. Supply chain disruptions can materialize from various areas, internal and external to supply chain.
- *Supply chain risk source*: It attempts to circumscribe supply chain disruptions (i.e. the demarcation of supply chain risks from other business risk). Many scholars have proposed classifications in the form of typologies or taxonomies of risks. The derived classes of supply chain disruptions are often labeled as supply chain risk sources.
- *Supply chain vulnerability:* While a supply chain disruption is the situation that leads to the occurrence of risk, it is not the sole determinant of the final result. It seems consequential that susceptibility of the supply chain to the harm of this situation is also of significant relevance. This leads to the concept of supply chain vulnerability. In other words, Christopher and Peck (2004) defined supply chain vulnerability as "an exposure to serious disturbance", while Barnes and Oloruntoba (2005) described vulnerability as "a susceptibility or predisposition to loss because of existing organizational or functional practices or conditions".

Hence, to sum up, supply chain risk management can be described as the process of managing the supply chain risks through coordination or collaboration among the supply chain partners, so as to avoid business failures and ensure profitability and continuity. Thus, the aim of risk management is to plan management strategy, detect risks, control failures, monitor the process of implementing risk management, audit and evaluate the results. All the countermeasures serve to safeguard continuity and maximize profitability (Tang, 2005). Additionally, the mechanism to deal with procurement risk management is often created through the agreement between buyers and suppliers with the purpose to avoid the damage caused by buyer uncertainty, system malfunction, buyer or supplier error, and product or service mismatch (Tang and Shee et al., 2001).

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Figure 1. The relationship of risks with components of supply chain

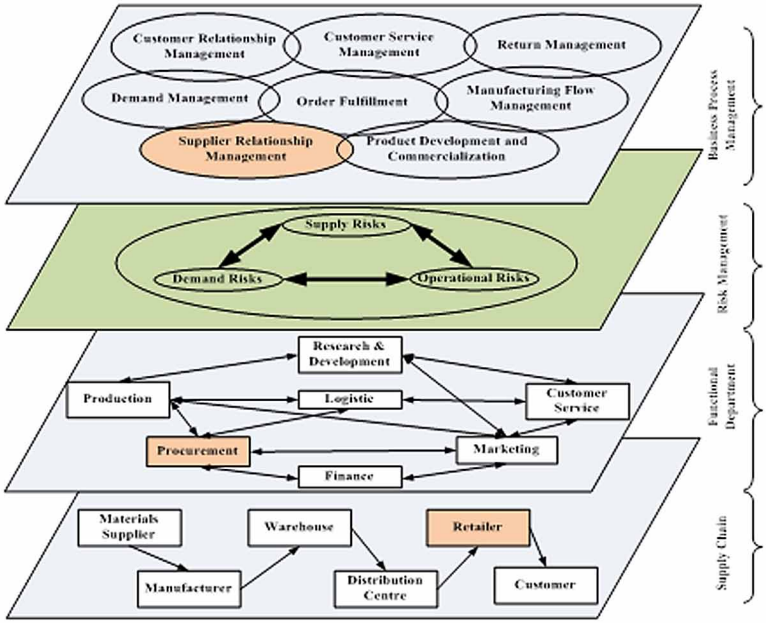

Figure 1 elaborates the relationship among supply chain activities, functional departments of a specific organization, business processes and risk management. Between functional department blueprint and business process frame, risk management can be understood as a combination of those two layers. It means that risk management can be integrated in all business processes and it is implicit that there is some specific work among different departments in an organization in order to reduce potential risks or errors. For example, risks should be studied and management plan be executed in Manufacturing Flow Management process. On the other side, for instance, logistic or transportation work department might mainly focus on reducing the risk of transportation cost, logistic collaboration and so on. Thereof, in the following paper, we study risk management of Supplier Relationship Management in Procurement process, especially for supplier selection.

As shown in the layer of risk management, there are three types of risks in supply chain: supply risks, demand risks and operational risks. Seeing the first layer at the bottom, these three risk categories might be found in all facilities through the supply chain. In the second layer which is functional department in an organization, risks are present in the real work of all functional activities. Accordingly, any of the business process on the top layer consists of large number of risks. In the process of Supplier Relationship Management, procurement department of retailer should mainly focus on reducing three kinds of risks: supply risks, demand risks and operational risks. However, risks in procurement are highly related with the specific activities.

According to the definition of procurement, its objectives are to purchase the right material with right quality, in the right quantity, at the right time, from the right source or right supplier and at the right price (Fernandez, 1995). Thus, according to the process map of procurement in Figure 2, tasks that should be focused on reducing risks are as follows:

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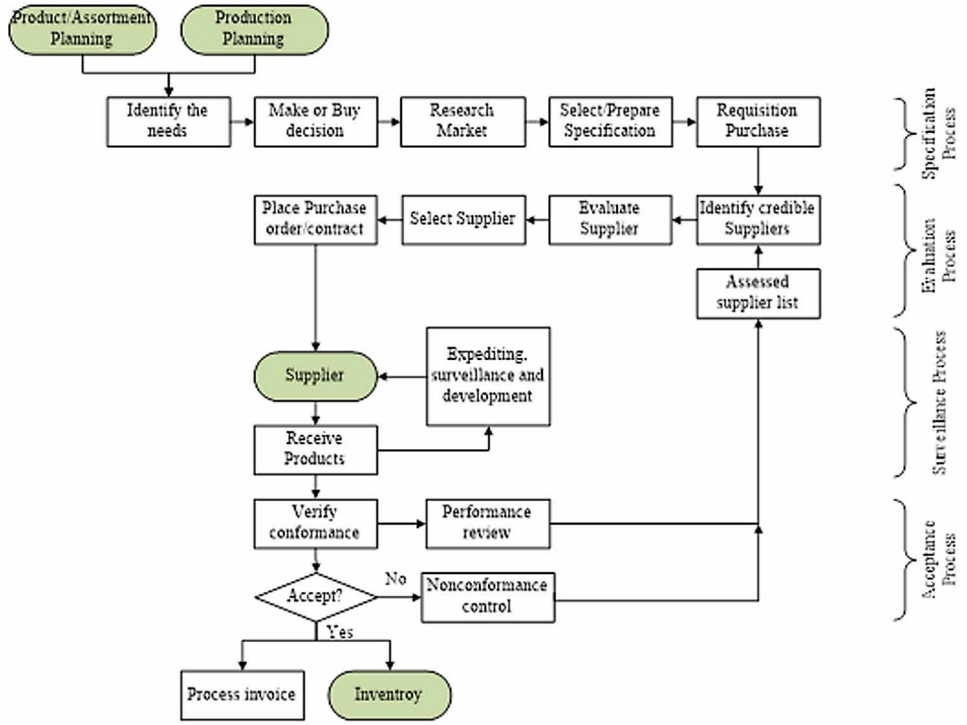
Figure 2. Procurement process map (derived from Hoyle, 2006)



- To supply the organization with steady flow of materials and services to meet its needs
- To ensure continuity of supply by maintaining effective relationship with existing sources and to develop other sources of supply either as alternatives or to meet emerging or planned needs
- To buy efficiently and wisely and obtain by any ethical means the best value for every pound spent
- To manage inventory so as to give the best possible service to users at lowest cost
- To maintain sound co-operative relationships with other departments, provide information and advice as necessary to ensure the effective operation of the organization as a whole
- To develop staff, policies, procedures and organization so as to ensure the achievement of the foregoing objectives
- To monitor and control the product quality and maintain the customer service level.

In this paper, we focus on the risks in the process of supplier selection in retail industry. Thereof, combined with activities in FMCG (Fast Moving Consumer Goods) commodity procurement process, three kinds of risks are summarized in Table 1.

As shown in Table 1, the risks indicated are risks not only for buyers or suppliers, some of them are risks for both of them. With these risks in procurement process, buyer and suppler need to cooperate together so as to detect, evaluate and reduce them. Furthermore, Farmer (1985) elaborated the contents of procurement in retail industry as follows:

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Table 1. Risks in FMCG purchasing

Supply Risk	Demand Risk	Operational Risk
High variability of supplying product quality	High variability of order demand	Lack the standard, mature work processes
Lack of flexibility of purchasing contract	Low accuracy of demand forecast	Inefficient communication and cooperation
Lack of enough productivity of product	Low order fulfillment	Lack of flexibility of pricing strategy
Lack of quick responsiveness from suppliers	Low fill rate	Lack of quality assurance and audit mechanism
Lack of technical or financial support	Long lead time	Lack of continuous improvement
		Lack of effective negotiation mechanism
		Low level of information sharing
		Lack of safety protection, sustainable mechanism

1. ***The product****:* New or scarce product planning and buying; Existing product eliminating.
2. ***The price:*** Key point of negotiation since the gross margin, percentage of profit between buying and selling prices are the one of principal factors concerned.
3. ***Payment terms:*** Cash flow may be difficult, or there may be a 'false' position for a company's year-end balance sheet.
4. ***Delivery and distribution:*** Company policy may dictate the desirability of delivery to individual shops or to regional/central warehouses or redistribution centers. It is important that the buyer has detailed knowledge of these costs in order that he can calculate whether the mix of buying prices, payment terms and delivery terms is the optimum in a particular circumstance.
5. ***Advertising promotion:*** The majority of retailers, however, acquire funds to cover their A&P (Advertising and promotion) from their suppliers. Many suppliers have come to expect this, and in all probability try to cost it into the buying price. Others, however, see product, price A&P etc., as having quite separate budgets, and the skilled buyer will seek to obtain maximum revenue from each source. Nevertheless, as with all forms of buying it is necessary to consider the whole mix – product, price, payment etc.

Hence, to manage those risks that exist in activities of procurement, Total Quality Management (TQM) is an efficient methodology to identify, monitor and reduce risks. Farmer (1985) defined that TQM is the collaboration work that includes every process, every job and each person to be involved in quality improvement to satisfy customers' requirements either in product or service performance. That is, in the process of supplier selection for a retailer, not only price factor and product (or service) quality should be considered to reduce the potential risks, but also supplier's business structure, financial status, quality assurance system, human resources etc. should be investigated so as to improve the reliability of supplier selection.

In the following sections, we study the approaches of supplier selection and analyze a real case by using single dimension weighted score ranking method to select suppliers. After that, an optimal multi-dimension weighted score ranking approach is proposed.

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2. RELATED WORK

Supplier selection, generally speaking in retail industry, faces the following purchasing decisions: What product to buy or eliminate? Which suppliers are qualified? How to make trade off among buyer and supplier? Around these topics of supplier selection, Najla et el. (2007) reviewed the processes of vendors selection, and also reviewed some popular models for selecting suppliers. De Boer et al. (2001 & 2003) elaborated an overview of supplier selection model. The process of supplier selection mainly includes the following:

1. Problem defining and purchasing target plan
2. Criteria for assessing supplier formulation
3. Pre-assessing of potential supplier
4. Final assessment to make decision

To make final decision, supplier might be selected by single criteria. Roodhooft and Konings (1996) suggested the use of the activity based costing approach (ABC) to compute total costs caused by a supplier in a firm's production process. As in Timmerman's model (1986), the system chooses the supplier who minimizes the total additional costs associated with the purchase decision (e.g., price differentials and supplementary estimated internal production costs caused by the supplier). A vendor evaluation can also be done by comparing budgeted and actual scores after delivery of the products. However, most assessments of supplier selection are done by multi-criteria approaches. Buyers select the best supplier taking into account the multi-objective nature of the factors. Wind and Robinson (1968) used linear weighting models to assess the vendor's performance. This approach produces useful and reasonably reliable data, and is relatively easier to implement. Tavana et al. (2016) proposed a hybrid ANFIS-ANN model to help departments in supplier evaluation process. Further, they used Multi-Layer Perceptron (MLP) process to predict and rank the suppliers' performance based on the most effective criteria. Zenz (1981) described a score method. That is, it consists of assigning weights to each criterion so that the highest score indicates the highest importance. After that, rankings on the criteria are multiplied by their weights and summed in order to obtain a single figure for each vendor. Finally, the supplier who has the best mark compared to the whole of the weighted criteria is chosen. Similarly, Cerna et al. (2016) used multi-criterion analysis with scoring model in suppliers' evaluation in the logistics company.

Furthermore, categorized by Degraeve et al. (2000) and De Boer et al. (2001) as a total cost approach, Monczka and Trecha (1988) combined this approach with rating systems for criteria such as service and delivery performance for which it is more difficult to obtain the cost figures. As a result, it proposed multiple criteria vendor service factor ratings and an overall supplier performance index using linear weighting models to adjust the net price for non performance costs associated with the supplier. Similarly, Smytka and Clemens (1993) developed a more elaborated total cost approach in which they first assess "risk factors" on a go/no-go basis. After that, they developed rates on several "business desirable factors" such as delivery performance. Finally, they collected information on a very extensive list of "measurable cost factors" and calculated the total cost. Simple linear weighting models have also been adapted to deal with uncertainty in decision making deriving from incomplete and qualitative data and unstructured purchasing situations (e.g., dynamic and subjective criteria and alternatives). For the major part of the proposed models, the common feature of the techniques is that we do not directly have to provide precise numerical parameters such as criteria weights.

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In the literature reviewed above, supplier selection might be decided by either a single or multi factors. Zak (2015) recommends that evaluation of suppliers in different industries should be done as a multiple criteria ranking problem. Further, based on the literature review, Ho et al. (2010) found that multi criteria decision making approaches are better than traditional cost-based approach.

Other Approaches in Supplier Selection and Evaluation

A structured literature review by Govindan et al. (2015) found fuzzy based single model approaches are used by most authors in supplier selection and environmental management system is the common criteria considered in green supplier selection. Zeydan et al. (2011) proposed an approach that considered both qualitative and quantitative variables in evaluating the supplier performance and evaluation quality. Qualitative performance evaluation is done using fuzzy AHP to find criteria weights and then fuzzy TOPSIS is applied to find rankings of suppliers. Lima-Junior et al. (2016) combined two fuzzy TOPSIS models to evaluate the suppliers in dimensions of cost and delivery performance. According to them, combining SCOR and fuzzy TOPSIS ha benefits such as it enables benchmarking against other SCs, brings agility to the decision process etc. Tang et al. (2015) proposed fuzzy preference relations (FPR) model to address the indefinite and inconsistent information to evaluate key supplier relationships and finally to select relevant suppliers.

Azadi et al. (2015) developed a data envelopment analysis (DEA) enhanced Russell measure (ERM) model to select the best sustainable suppliers. The proposed model further helps to deal with economic, social, and environmental factors when selecting suppliers. Dobos et al. (2014) suggested mixed Data envelopment analysis and composite indicator method to investigate the environmental aspects in supplier selection. Hosseininasab et al. (2015) introduced a supplier selection method based on the long term trend of value, stability, and relationship of potential suppliers. As compared to already available methods, this method selects higher value suppliers with lower risk of failure. Jadidi et al. (2015) proposed a multi choice goal programming approach that provides decision maker with more control over preferences in considering supplier selection. The research found that most popular approach used is Data Envelopment Analysis (DEA). Further, the research found quality as the most popular criterion in supplier selection. Vaidya et al. (2013) proposed a multi criteria decision tool based on AHP for supplier performance valuation. This approach considers multiple criteria and also provides flexibility to modify the available data sets.

Chen et al. (2011) presented a structured approach that established key evaluation criteria and indicators and then used DEA and TOPSIS to filter and evaluate potential suppliers. Similarly Kang et al. (2010) proposed a model based on AHP and Data Envelopment analysis. The authors used DEA to evaluate quantitative factors and AHP analysis is used to evaluate qualitative factors. However, final ranking is obtained by comparing qualitative and quantitative results. Thakur et al. (2015) proposed a multi-attribute decision-making (MADM) based on grey theory that is used to select the relevant supplier when certain information is unavailable. The grey theory model can be applied in all the situations in service industries when exact quantified values are unavailable. Also, Yadav et al. (2015) proposed a fuzzy analytical hierarchy process (FAHP) that can be useful for supplier selection when there are inconsistencies observed (Dynamic situations) in the data.

Quality management perception has also been applied on the process of supplier selection. Carter et el. (1998) used TQM approach to manage the buyer-supplier relationship. In their literature, they focused on the procurement process, supplier interaction, human resources, competitive factors and or-

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ganization structure to improve the performance of supplier relationship. Tidwell et al. (2012) employed Quality Function Deployment (QFD) method to analyze the problem of supplier selection. The results show that QFD process led to a rapid identification of suppliers that are most capable of providing the product characteristics that met the corporate total value goal. Dey et al. (2015) used integrated analytical model that combined quality function deployment and the analytic hierarchy process for supplier's performance evaluation. Additionally, they also proposed leading (organizational practices, risk management, environmental and social practices) and lagging factors (quality, delivery schedule and value/cost) for supplier evaluation. Quality management practices in supplier relationship management and rating suppliers have been researched by Part et al. (2001). Likewise, Caddick et al. (1998) studied the impact of total quality management on the purchasing function. These both the literatures suggest that quality factors are involved in supplier relationship management so as to reduce potential risks in procurement.

Thus, in this paper, we analyze the method of a real case to assess supplier in retail industry. The common quality concepts have been introduced in the case, though its performance and reliability should be evaluated and improved by TQM.

3. RESEARCH METHODOLOGY

In this section, we introduce a real case of supplier selection. The case uses weighted score rating method to classify suppliers by different rankings. Then considering the rankings, the senior buyer and procurement manager might make decision to select the specific suppliers or eliminate those who are evaluated by low rankings. After analyzing this case, we propose a new approach by using TQM perception to establish a considerable process of supplier selection.

3.1 Background

ABC Co., Ltd. (this pseudo name as the privacy policy) commenced its business in Shanghai twenty years ago. During the past years, through direct operations, franchises, mergers and acquisitions, it has developed into a nationwide chain retail operator with a full range of retail segments in China. As on 31 December 2008, this company and its subsidiaries operated a total of 3,872 outlets (excluding those operated by the Company's associated companies) spanning in 20 provinces and municipalities across the nation. The Company continues to maintain its leading position in the fast moving consumer goods (FMCG) chain in the People's Republic of China. ABC is one of companies listed on Hong Kong Stock Exchange as the retail operator.

The Group operates three main segments of retail outlet brands, namely hypermarkets, supermarkets and convenience stores, catering to the diverse needs of consumers.

In one of the ABC's branches (called BA in this paper), its procurement department is dependently managing over 2275 suppliers and purchasing approximately 100,000 kinds of commodities a year. In purchasing department, there are hundreds of employees working on supplier selection, supply contract negotiation and assortment management. BA's total sales margin was over 8 billion in 2008. Moreover, in 2009 year, the total value of purchasing commodities on contracts was over 9.3 billion managed by the procurement department (The financial report, 2009: we can provide data with privacy agreement if someone is interested in this research.). Further, data from 2009 showed that 115 out of 2275 suppliers have been eliminated. Although it is only 5.05%, it still indicates there is high variability in BA's supplier

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Table 2. Multi factors and weighted ratio used to rank supplier in BA's current system

Factors to be evaluated supplier performance			Points (Weighted Ratio)
ID	**Initial**	**Factor Name**	
1	TSQ	The Performance of Total Sales Quantity	15
2	TSM	The Performance of Total Sales Margin	30
3	PA	The Performance of Profitability	20
4	ITR	The Performance of Inventory Turnover Rate	8
5	NDD	Delivery Performance with No Deficiency	5
6	RR	The Performance of Return Rate	2
7	PR	The Performance of Promotion Resources Provided	5
8	PI	The Performance of Price Index	5
9	PQ	The Performance of Product Quality	5
10	OA	The Performance of Organization Operation Ability	5
Total			**100**

relationship. Thereof, it is important and crucial to design an approach to improve supplier relationship management so as to develop a stable partnership with suppliers. Under such pressure, BA's buyers and procurement managers are facing the following problems:

- How to effectively select the suppliers deserved to supply products as new suppliers?
- How to effectively eliminate those suppliers who contributed lower profits and higher risks from current suppliers list?
- How to avoid the potential risks in supplier selection or from supplier's side?
- How to establish a sustainable relationship with suppliers?

Therefore, focusing on above issues, the following sections will be conducted to achieve the desired results.

3.2 Problem Definition

In the single dimension (linear) weighted score rating method, BA's suppliers have been classified by 5 rankings as AA, A, B, C and D. Those five ranking numbers have been assigned by assorting the ranking scores which are calculated by summing up the point of each unit multiplied by the different weight. In Table 2, all the factors that decide the supplier performance, with different weights, have been listed.

According to the background introduction, BA is a FMCG retailer, that is, it purchases large amount of commodities with price ranging from few cents to thousand dollars per item and with large quantity. Table 2 indicates that the Total Sales Quantity (15%), Total Sales Margin (30%) and Profitability (20%) are most important factors that influenced BA's current business performance, since the total ratio of those three factors is 65 out 100. The ratio of rest 7 factors is 35 out 100. To evaluate the performance of this current weighted score ranking method, we provide an original sample dataset which is abstracted from 20 suppliers' first 10 months' sales data in 2009, and it's listed in Table 3. Further, by using the simple linear weighted ranking method, the result of ranking suppliers in terms of the relative data in Table 3 has been determined in Table 4.

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Table 3. 10 months sales data of 20 sample suppliers in 2009

Supplier ID	Sales Quantity	Total Sales	Gross Profit	Fee for Store	Fee for Contract	Total Fee	Total Profit	Turnover Days	Fill Rate	Return Rate	Promotion Resource	Price Compliant
1	9347	2234607	248339	64711.2	115414.4	180125.6	428464.6	0.85	0.900901	0.568005	1	0
2	62229	4283505	708431.5	76926.56	784602.4	861529	1569960	96.45	0.960884	0.495724	92	0
3	410118.38	437406.2	103831.2	2832	148711.2	151543.2	255374.5	16.53	0.959747	0.047792	54	0
4	2185	82435.85	20587.48	0	0	0	20587.48	220.89	0.793428	0.010327	0	0
5	90154	1489583	272181.7	19139.6	569348.2	588487.8	860669.5	47.69	0.999911	0.058498	15	0
6	156647	737168.9	124164.6	283.2	69687.56	69970.76	194135.3	46.16	0.988776	0.048814	377	0
7	1107420	7565149	592286.7	197343.2	1343512	1540856	2133142	38.04	0.930517	0.046255	11	85
8	56740	318239.4	11091.55	0	176271.5	176271.5	187363	53.35	0.972328	0.044824	3	7
9	22836	3047193	555406.7	148623.4	412266.2	560889.6	1116296	34.24	0.980611	0.149106	90	6
10	298	12081.01	2721.01	0	0	0	2721.01	400.78	0.229277	0.436197	0	0
11	2333447	18788127	2703416	79956.8	2525271	2605228	5308644	17.72	0.956886	0.051981	271	0
12	4074720	12227206	1727943	125179.1	2194958	2320137	4048081	31.32	0.989928	0.032484	218	3
13	111456	2862856	429885.2	17246.88	903577	920823.9	1350709	45.17	0.987516	0.053343	17	0
14	226789	12525411	1620859	217091.7	1896996	2114087	3734946	59.25	0.924884	0.233852	51	40
15	1983039	13064870	1439869	32029.92	1808190	1840220	3280089	22.46	0.954216	0.036922	53	5
16	36247	419443.8	51929.46	0	84612.24	84612.24	136541.7	101.42	0.960974	0.042969	27	0
17	3259009	7740513	975545.6	120039	1014008	1134047	2109593	26.17	0.952629	0.084071	127	0
18	2073918	4811265	736487.6	20012.8	165200	185212.8	921700.4	15.33	0.595578	0.006753	6	0
19	852933.6	9001395	1209672	114044.6	1635891	1749935	2959608	11.5	0.990627	0.011746	12	3
20	7746665	30565678	1966523	336186.7	2761117	3097304	5063826	17.42	0.952381	0	309	119

Table 4 shows the suppliers performance ranked as class AA, A, B or C etc. that indicates performance level from higher to lower. The different ranking numbers are used to classify suppliers. However, in the current system, those suppliers' who are assigned class D should be eliminated from the supplier list for next purchasing year/period. It implies that those suppliers who get rank D might not be permitted to continue supply commodities to BA in terms of their worse sales or other bad records. However, those suppliers who get rank AA or A, does not mean that all their performance criteria are perfect but there may be some risks still needed to be monitored and improved. Although those scores have been calculated out, the ranking (alphabet) number is assigned by somehow strategy objective. For example, Supplier 15 has the total score of 71.71 and its value is larger than Supplier 14 (70.21, assigned as AA

Table 4. Results of ranking suppliers by using simple linear weighted method

Performance		Supplier Evaluated																			
ID	Factor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	TSQ	8.96	8.97	8.96	8.95	8.98	8.98	9.25	8.97	8.96	8.95	9.46	9.94	8.98	9.01	9.47	8.96	8.99	8.98	9.08	11.05
2	TSM	18.04	18.14	17.89	17.88	17.99	17.91	18.43	17.90	18.10	17.88	19.01	18.61	18.09	18.79	18.77	17.91	18.18	18.05	18.21	20.11
3	PA	12.05	12.42	11.92	11.89	12.22	11.93	12.74	11.95	12.33	11.88	13.68	13.22	12.42	13.38	13.12	11.93	12.38	12.04	12.50	13.91
4	ITR	8.00	7.64	6.84	7.18	7.82	7.83	7.86	7.81	7.87	6.51	7.93	7.88	7.83	7.78	7.92	7.62	7.90	4.51	7.96	7.94
5	NDD	4.50	4.76	4.79	3.97	5.00	4.94	4.65	4.86	4.90	1.18	4.75	4.93	4.94	4.62	4.77	4.80	4.72	1.62	4.95	4.76
6	RR	0.86	1.04	1.91	1.98	1.88	1.92	1.91	1.91	1.70	1.20	1.90	1.94	1.89	1.53	1.93	1.91	1.83	1.99	1.98	2.00
7	PR	2.99	3.00	3.00	2.99	3.00	3.09	2.99	2.99	3.02	2.99	3.02	3.00	3.00	3.01	3.01	3.00	2.99	2.99	2.99	3.09
8	PF	2.99	2.99	2.99	2.99	2.99	2.99	3.18	3.01	3.01	2.99	2.99	3.00	2.99	3.08	3.00	2.99	2.99	2.99	3.00	3.26
9	PQ	4.90	4.08	4.02	3.00	4.00	4.00	5.00	5.00	4.00	3.75	3.97	4.77	5.00	4.00	4.88	5.00	4.07	4.49	2.84	4.00
10	OA	4.90	0.43	2.70	3.00	3.00	1.62	5.00	4.00	3.00	2.41	3.95	4.77	4.00	5.00	4.86	4.00	3.17	3.95	2.27	5.00
Total Score		68.19	63.46	65.01	63.83	66.88	65.21	71.01	68.40	66.88	59.74	70.66	72.08	69.14	70.21	71.71	68.14	67.22	61.61	65.77	75.12
Rank		B	C	C	C	B	B	AA	A	B	C	B	AA	A	AA	B	B	B	C	B	AA

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class), however it is the B class supplier since its profitability is lower, and sales quantity is high though. Therefore, this means those weighted score results are only references of final ranking (alphabet) numbers.

In Table 3, historical data for only 20 suppliers' is listed as prototype because there are huge datasets of 2275 suppliers and over 100,000 commodities purchased in 2009. Thus, due to this nature reason and data privacy, the 20 datasets are shown instead of the entire historical data, though the data analysis approach might be applied to all of them. In order to well understand the data characteristics, there are some notations that should be defined:

- *Gross Profit:* Indicates the profit by total sales minus the contract revenue.
- *Fee for Store:* Indicates the fee charged by independent stores. It is the one of the profits.
- *Fee for Contract:* Indicates the fee charged to suppliers who are qualified to supply commodities.
- *Total Profit: T*otal of gross profit and fees.
- *Promotion Resource: A*bility of suppliers to participate promotions with retailer.
- *Price Compliant:* Indicates suppliers didn't maintain the stability of contract price.

As the first part to conduct weighted score ranking method, at the end of the previous year, BA's procurement department plans the targets of sales quantity, total sales and increasing of total profits for next year. Thus, the level of those goals achieved at the end of next year is used to assess supplier's performance as TSQ, TSM and PA. That is, the scores are assigned in terms of the degree of goals achieved by suppliers. For example, supplier 1 has the goal to sale 15648 items during 2009; however, it only reached 59.73% of that goal, that is, it finally sold 9347 items. Thereof, the score of TSQ is equal to 8.96 which is 59.73% of 15 points. Likewise, the score of TSM and PA can be calculated. Furthermore,

ITR=8×inventory turnover rate;
NDD=5×Delivery Rate with no deficiency, and
RR=2×(1-Return Rate).

The score of PR is decided by ratio of total promotion times participated to total promotion times held by BA.

PI=5×price rating provided by marketing research organization.
PQ=5× (1-Product Defect Rate inspected).

The score of OA is subjectively decided by the information related with the registered capital of organizations, how long they have done business together, how its sales and profits is increasing or declining and so on.

This method provides a serial of criteria to assess supplier. However, by using this single dimension (linear) weighted ranking method, there are some issues such as:

1. How to identify whether assigned ratios are scientific or reasonable?
2. Whether the process of supplier selection has maximally avoided the potential risks?
3. How to involve most factors that influenced business performance for evaluating supplier?
4. How to apply quality management elements in supplier selection?

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5. How to easily find the crucial problems for those strategy suppliers having lower ranking number, to help them improve their quality or reduce the risks?

Although, the process of supplier selection should mainly focus on total sales and profitability, sales quantity should not be excessively weighted since the retailer may have different strategies with different products even for those products that probably could be sold as small portions. Therefore, the following section proposes a systematical TQM based multi-dimension approach in order to establish a new method of supplier selection.

3.3 Approach

As the first step of proposed approach, we define the scope for assessing suppliers, that is, all the factors which are used to evaluate the supplier's performance. This scope contains many aspects by considering TQM in the process of supplier selection. In Table 5, all factors used to assess suppliers have been categorized. Some of the factors might be evaluated by data; however, others only can be estimated by empirically qualifying criteria. To implement TQM concepts in supplier selection in terms of the special requirements of retail supply chain performance, we propose that all five categories of suppliers assessed should be assigned the different weights which are approximate with the weighted ratios used in BA's current ranking system. In this case, we continuously use the idea that the weights are assigned in Table 4. However, each factor in a category might use different ratios since those factors have different contributions in that category. This issue will be researched in following paragraphs.

Secondly, we have established the framework for evaluating suppliers by complying with the empirical weights (approximate with the weight ratios of BA's current ranking system) assigned for each category, though the weight of each factor in a category should be determined corresponding with the principals of BA's current ranking system. In order to establish the weight of each factor in a category, we use Principal Component Analysis (PCA) to identify the ratios of those factors by real datasets. To examine the ratio of each factor for assessing suppliers, we apply PCA for data reduction in SPSS. Before conducting this analysis, we propose an approach to standardize the data that is more meaningful and understandable by following definitions in Table 6. According to definitions of standardizing data in Table 6, data in Table 7 has been standardized in terms of the original data in Table 3.

There is a lot of literature about Principal Component Analysis (PCA) method used to reduce data dimensions (Montgomery, 2005). Further, it has been studied to apply on supplier selection (Alberto et al., 2000). In this case, we categorize those standardized original datasets as three groups, that is, "Revenue", "Quality" and "Price". There is no data available for "Service" and "Organization" in current original datasets, though it will not influence the result of analyzing the ratios of each factor in each category for current data. Analyzing "Revenue" data by PCA, we identify the ratios for each factor of "Revenue" category in Table 5. Likewise, the weight number is determined after applying PCA to analyze "Quality" and "Price" performances.

Table 8 and Figure 3 show that the ability of contributing profits is the most important factor of supplier selection among 4 factors of revenue performance. Thereof, firstly we consider that total profit is better than total sales. This is natural and reasonable because profit is the first crucial thing as business operation, otherwise the companies may not survive without gains even if there are good sales. Then, we adjust the ratios as: 65% for total profits, 20% for total sales, 10% for total fees and 5% for total sale quantity.

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Table 5. Framework of TQM based multi-dimensional approach for assessing suppliers

Category	Factors for performance evaluated
Revenue	1. The total profits
60%	2. The total sales
	3. The total fees charged from suppliers
	4. The total sales quantity
Service	1. The ability to fulfill delivery due date
10%	2. Delivery the right amounts
	3. The ability for technical support
	4. The ability for marketing and sales support
Quality	1. Product quality conformance rate
10%	2. Return rate
	3. Customer compliant with product quality
	4. Production capability or supply ability
	5. Contract fulfillment
Price	1. Price stability
10%	2. Price compliant
	3. Promotion conducting
Organization	1. Financial stability
10%	2. Business records with together cooperation
	3. Mature business operation process and quality assurance system
	4. Organization geographic allocation
	5. Organization human resource support

Table 9 and Figure 4 show that the product quality performance has been decided by the different ratios among product conforming rate, fill rate and return rate. It is obvious that the performance of product quality is the most important factor to assess supplier in terms of product quality characteristics. Product conforming rate has been separated as two factors, that is, supply capacity (with 50% weight) and product defects inspected (with 20% weight). Contract fulfillment performance is about 20% of total weights, 5% for customer compliant and another 5% of total percentage for product returns (both returns for damaged products in delivery and returns for expiration).

Moreover, Table 10 shows the weight relationship between promotion resources and price complaints. Most performance of price can be decided by promotion resources which are applied on discounts or mass sales by different price strategies, and so on. Ratios of factors in this "Price" category should be adjusted, since we should specify the factors and add more. Thus, 50% of total weights are about "Price Stability", 35% for "Price Compliant" and 15% for "Price Promotion". In this case, we adjust the ratio as total 65% weight instead of 72.607% in original dataset.

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Table 6. Notation and definition of standardizing original datasets

Factor	Definition	Description
S_SQ	Standardized Sales Quantity	This is 2275*ratio of individual quantity divided by sum of totals
S_TS	Standardized Total Sales	This is 2275*ratio of individual sales divided by sum of totals
S_GP	Standardized Gross Profit	This is 2275*ratio of individual profits divided by sum of them
S_FS	Standardized Fee for Store	This is 2275*ratio of individual fee for store divided by sum of them
S_FC	Standardized Fee for Contract	This is 2275*ratio of individual contract fee divided by sum of them
S_TF	Standardized Total Fee	This is 2275*ratio of individual total fee divided by sum of them
S_TP	Standardized Total Profit	This is 2275*ratio of individual total profit divided by sum of them
S_TD	Standardized Turnover Days	This is 2275*ratio of individual turnover day divided by sum of them
FR	Fill Rate	This is the original data
RR	Return Rate	This is the original data
S_PR	Standardized Promotion Resource	This is 2275*ratio of individual resource number divided by all totals
S_PC	Standardized Price Compliant	This is 2275*ratio of individual compliant number divided by totals
PDI	Product defects inspected rate	This is the original data
BOA	Business operation ability	This is the original data

Finally, we propose an approach called as Multi-Performance and Multi-Factor Assessment (MPMFA) method in terms of implementing this TQM based multi-dimension approach in supplier selection. As shown in Table 11, there are five critical performance criteria used to assess suppliers by assigning different ratios. In previous paragraphs, we have elaborated that "Revenue" performance is the most important dimension to evaluate suppliers in FMCG retail industry, since retailers are naturally and reasonably concerned about the profit returned from each item sold because FMCG business is highly related with

Table 7. Standardized original historical datasets

Supplier	S_SQ	S_TS	S_GP	S_FS	S_FC	S_TF	S_TP	S_TD	FR	RR	S_PR	S_PC	PDI	BOA
1	0.031137	0.774135	0.864355	1.264147	0.636529	0.774707	0.824257	0.001192	0.90090	0.56801	0.021187	0	0.98000	0.98000
2	0.207296	1.483934	2.465727	1.502777	4.327212	3.705376	3.020204	0.13527	0.96088	0.49572	1.949225	0	0.81649	0.08506
3	0.13664	0.151531	0.361389	0.055324	0.820167	0.651777	0.491275	0.023183	0.95975	0.04779	1.14411	0	0.80499	0.54084
4	0.007279	0.028558	0.071656	0	0	0	0.039605	0.309797	0.79343	0.01033	0	0	0.60000	0.60000
5	0.300319	0.516036	0.94734	0.373896	3.140049	2.531045	1.655709	0.066885	0.99991	0.05850	0.317808	0	0.80000	0.60000
6	0.52182	0.255377	0.43216	0.005532	0.384338	0.300939	0.373467	0.064739	0.98878	0.04881	7.987586	0	0.80000	0.32498
7	3.689019	2.620794	2.06148	3.855142	7.409692	6.627112	4.103623	0.053351	0.93052	0.04625	0.23306	13.87295	1.00000	1.00000
8	0.189011	0.110248	0.038605	0	0.972166	0.758131	0.360439	0.074823	0.97233	0.04482	0.063562	1.142478	1.00000	0.80000
9	0.076071	1.055639	1.933117	2.903389	2.273716	2.412347	2.14747	0.048021	0.98061	0.14911	1.906851	0.979267	0.80010	0.59981
10	0.000993	0.004185	0.009471	0	0	0	0.005235	0.562091	0.22928	0.43620	0	0	0.74959	0.48279
11	7.77314	6.508769	9.409358	1.561973	13.92729	11.2049	10.21248	0.024852	0.95689	0.05198	5.741739	0	0.79382	0.78967
12	13.57364	4.23587	6.014182	2.445401	12.10556	9.978748	7.787477	0.043926	0.98993	0.03248	4.618816	0.489633	0.95497	0.95497
13	0.37128	0.991779	1.496234	0.336922	4.983376	3.960399	2.59842	0.063351	0.98752	0.05334	0.360183	0	1.00000	0.80000
14	0.755476	4.339177	5.64147	4.240933	10.46224	9.092542	7.185086	0.083098	0.92488	0.23385	1.080549	6.528445	0.80000	1.00000
15	6.605866	4.526062	5.011527	0.625711	9.972468	7.914659	6.310057	0.0315	0.95422	0.03692	1.122923	0.816056	0.97515	0.97136
16	0.120745	0.145308	0.180743	0	0.46665	0.363911	0.262671	0.142241	0.96097	0.04297	0.572055	0	1.00000	0.80000
17	1.085635	2.681545	3.395429	2.344988	5.592423	4.877458	4.05832	0.036703	0.95263	0.08407	2.690778	0	0.81386	0.63331
18	0.69086	1.666766	2.563377	0.390954	0.911105	0.796587	1.773117	0.0215	0.59558	0.00675	0.127123	0	0.89814	0.78960
19	2.841278	3.118353	4.210317	2.227887	9.022207	7.526349	5.693532	0.016129	0.99063	0.01175	0.254247	0.489633	0.56719	0.45375
20	25.80556	10.58887	6.844568	6.56748	15.22801	13.32129	9.741513	0.024431	0.95238	0.00000	6.546854	19.42212	0.80000	1.00000

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Table 8. Total variance explained (revenue)

Component		Initial Eigenvalues		
		Total	% of Variance	Cumulative %
Raw	1 (S_TP)	28.635	76.704	76.704
	2 (S_TS)	5.669	15.185	91.889
	3 (S_TF)	2.606	6.982	98.871
	4 (S_SQ)	.422	1.129	100.000
Rescaled	1	28.635	76.704	76.704
	2	5.669	15.185	91.889
	3	2.606	6.982	98.871
	4	.422	1.129	100.000

sales activities but not production. Hence, 60% of weights are assigned to "Revenue" performance. The rest four criteria are also assigned with specific ratios by the assumption that those four criteria evenly influence the supplier performance.

Accordingly, based on the results of PCA, each factor has been correspondingly assigned a unique weight for each performance item (see Table 12). It should be noted that most factors might be quantified by data from POS or IIS (Integrated Information System), however some of them can only be qualified by the information gathered from questionnaires or dispersed market reports.

To sum up, MPMFA approach can be described as the equitation 1-1:

$$Ranking(P,F) = \sum_{i=1}^{5}\sum_{j=1}^{5} P_i F_j \,, \tag{1}$$

Figure 3. Eigenvalue plot

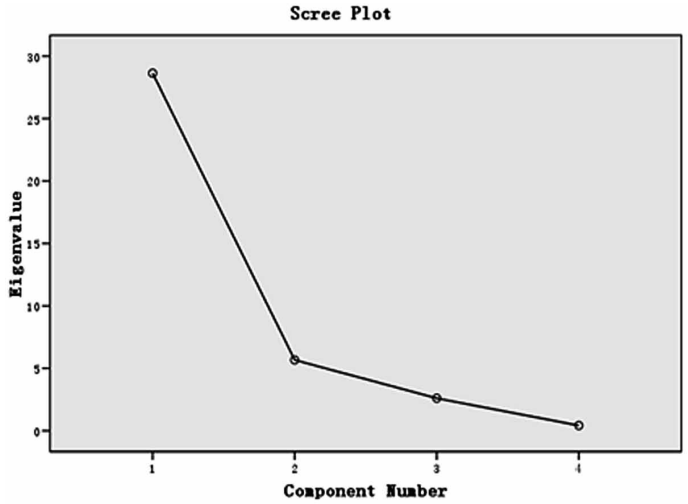

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Table 9. Total variance explained (quality)

Component		Initial Eigenvalues		
		Total	% of Variance	Cumulative %
Raw	1 (PDI)	.405	60.718	60.718
	2 (FR)	.199	29.878	90.596
	3 (RR)	.063	9.404	100.000
Rescaled	1	.405	60.718	60.718
	2	.199	29.878	90.596
	3	.063	9.404	100.000

Figure 4. Eigenvalue plot

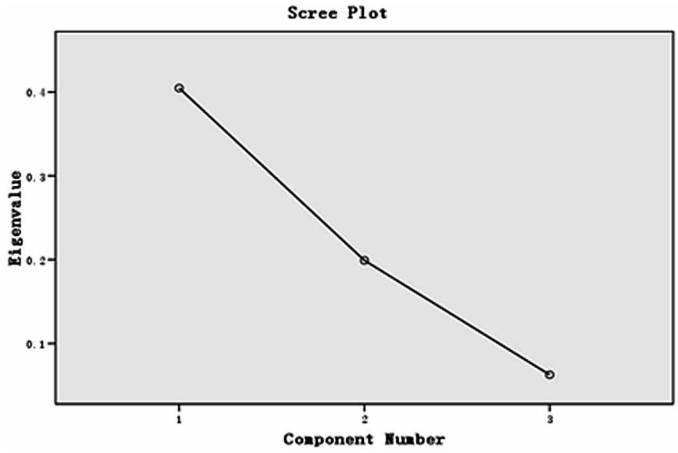

Table 10. Total variance explained (price)

Component		Initial Eigenvalues		
		Total	% of Variance	Cumulative %
Raw	1 (S_PR)	78.995	72.607	72.607
	2 (S_PC)	29.803	27.393	100.000
Rescaled	1	78.995	72.607	72.607
	2	29.803	27.393	100.000

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Table 11. Multi-Performance Criteria for Assessing Supplier

Performance Category	Value	Proportional Value
Revenue	60	0.60
Service	10	0.10
Quality	10	0.10
Price	10	0.10
Organization	10	0.10
Total	100	1.00

where, P_i stands for the i^{th} performance criteria; F_j stands for the j^{th} factor criteria; i and j are the number of performances and factors.

Note that some values may be unavailable, MPMFA assigns those values as 0. However, this paper strongly suggests that supplier selection decision making should consider all the performance criteria and weighted factors so as to fulfill the TQM philosophy. In this case, we use the same sample data as in Table 3 to explain how to use MPMFA approach.

Table 13 is the result of supplier selection by using MPMFA approach with the same sample datasets as used in Table 3. It shows the final score of assessing each supplier instead of ranking as alphabets (AA, A, B, C and D). If buyer wants to see the clear results by alphabetizing, it only needs to set a scope with a specific score which is assigned by alphabets, and then buyer may choose or eliminate suppliers. However, as a full proposed approach, MPMFA is better to evaluate suppliers by unique score numbers, because there may be some specific continuous improvements that might be implemented to help those suppliers avoid losing points in corresponding factors. In the following section, we propose an improvement plan for buyers to implement MPMFA approach in real work situation.

Firstly, it should be noted that all the column's value is "0", which mean those data requested are not included in current historical dataset. Those data should be gathered by customer survey, supplier survey or from IT department. Secondly, the "Total Score" is depicted instead of ranking number as AA or A etc. With the precise score numbers, BA can clearly compare those suppliers' 5 main category

Table 12. Multi-factor criteria for evaluating each performance

Performance Assessed		**Factor with Weight**				
ID	**Category**	**F1**	**F2**	**F3**	**F4**	**F5**
P1	***Revenue***	Total Profits 0.65	Total Sales 0.20	Total Fees 0.10	Sales Quantity 0.05	—
P2	***Service***	Delivery Due Date 0.30	Order Fulfill 0.30	Technical Support 0.20	Sales Support 0.20	—
P3	***Quality***	Supply Capacity 0.50	Defects Inspected 0.20	Contract Fulfillment 0.20	Customer Compliant 0.05	Product Return 0.05
P4	***Price***	Price Stability 0.50	Price Compliant 0.35	Price Promotion 0.15	—	—
P5	***Organization***	Years Cooperation 0.40	Registered Capital 0.30	Quality Certification 0.20	Office Allocation 0.05	HR Ability 0.05

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Table 13a. Supplier selection results by MPMFA approach

Suppliers	Revenue (60 Points)				Service (10 Points)			
ID	Total Profits 0.65	Total Sales 0.2	Total Fees 0.1	Sales Quantity 0.05	Delivery Due Date 0.3	Order Fulfill 0.3	Technical Support 0.2	Sales Support 0.2
1	0.60251	0.60133	0.00000	0.59701	0.90090	0.90090	0.00000	0.00000
2	0.62095	0.60467	0.00000	0.59782	0.96088	0.95125	0.00000	0.00000
3	0.59578	0.59617	0.00000	0.59701	0.95975	0.95840	0.00000	0.00000
4	0.59431	0.59610	0.00000	0.59688	0.79343	0.79369	0.00000	0.00000
5	0.61119	0.59952	0.00000	0.59846	0.99991	0.99991	0.00000	0.00000
6	0.59653	0.59710	0.00000	0.59866	0.98878	0.98832	0.00000	0.00000
7	0.63676	0.61430	0.00000	0.61680	0.93052	0.93052	0.00000	0.00000
8	0.59766	0.59667	0.00000	0.59786	0.97233	0.97233	0.00000	0.00000
9	0.61631	0.60330	0.00000	0.59725	0.98061	0.98014	0.00000	0.00000
10	0.59392	0.59591	0.00000	0.59684	0.22928	0.23503	0.00000	0.00000
11	0.68390	0.63381	0.00000	0.63050	0.95689	0.94984	0.00000	0.00000
12	0.66105	0.62039	0.00000	0.66273	0.98993	0.98582	0.00000	0.00000
13	0.62104	0.60286	0.00000	0.59885	0.98752	0.98752	0.00000	0.00000
14	0.66894	0.62637	0.00000	0.60093	0.92488	0.92488	0.00000	0.00000
15	0.65587	0.62568	0.00000	0.63109	0.95422	0.95484	0.00000	0.00000
16	0.59664	0.59692	0.00000	0.59749	0.96097	0.96097	0.00000	0.00000
17	0.61881	0.60594	0.00000	0.59942	0.95263	0.94331	0.00000	0.00000
18	0.60219	0.60153	0.00000	0.59854	0.59558	0.32324	0.00000	0.00000
19	0.62502	0.60705	0.00000	0.60534	0.99063	0.98987	0.00000	0.00000
20	0.69565	0.67027	0.00000	0.73651	0.95238	0.95238	0.00000	0.00000

Table 13b. Supplier selection results by MPMFA approach

Quality (10 Points)					Price (10 Points)		
Supply Capacity 0.5	Defects Inspected 0.2	Contract Fulfillment 0.2	Customer Compliant 0.05	Product Return 0.05	Price Stability 0.5	Price Compliant 0.35	Price Promotion 0.15
0.98000	0.00000	0.00000	0.00000	0.43199	0.59841	0.00000	0.59823
0.81649	0.00000	0.00000	0.00000	0.51755	0.59841	0.00000	0.59952
0.80499	0.00000	0.00000	0.00000	0.95374	0.59841	0.00000	0.59938
0.60000	0.00000	0.00000	0.00000	0.98967	0.59841	0.00000	0.59816
0.80000	0.00000	0.00000	0.00000	0.94150	0.59841	0.00000	0.59916
0.80000	0.00000	0.00000	0.00000	0.95756	0.59841	0.00000	0.61802
1.00000	0.00000	0.00000	0.00000	0.95375	0.63615	0.00000	0.59890
1.00000	0.00000	0.00000	0.00000	0.95518	0.60152	0.00000	0.59836
0.80010	0.00000	0.00000	0.00000	0.85096	0.60107	0.00000	0.60416
0.74959	0.00000	0.00000	0.00000	0.60012	0.59841	0.00000	0.59816
0.79382	0.00000	0.00000	0.00000	0.94808	0.59841	0.00000	0.60358
0.95497	0.00000	0.00000	0.00000	0.97017	0.59962	0.00000	0.60007
1.00000	0.00000	0.00000	0.00000	0.94666	0.59841	0.00000	0.59930
0.80000	0.00000	0.00000	0.00000	0.76615	0.61617	0.00000	0.60156
0.97515	0.00000	0.00000	0.00000	0.96316	0.60056	0.00000	0.60139
1.00000	0.00000	0.00000	0.00000	0.95703	0.59841	0.00000	0.59996
0.81386	0.00000	0.00000	0.00000	0.91613	0.59841	0.00000	0.59870
0.89814	0.00000	0.00000	0.00000	0.99634	0.59841	0.00000	0.59838
0.56719	0.00000	0.00000	0.00000	0.98836	0.59917	0.00000	0.59859
0.80000	0.00000	0.00000	0.00000	1.00000	0.65124	0.00000	0.61876

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Table 13c. Supplier selection results by MPMFA approach

Organization (10 Points)					Total Score
Years Cooperation 0.4	Registered Capital 0.3	Quality Certification 0.2	Office Allocation 0.05	HR Ability 0.05	
0.98000	0.00000	0.00000	0.00000	0.00000	50.83559835
0.08506	0.00000	0.00000	0.00000	0.00000	47.57570301
0.54084	0.00000	0.00000	0.00000	0.00000	48.49141031
0.60000	0.00000	0.00000	0.00000	0.00000	46.66741599
0.60000	0.00000	0.00000	0.00000	0.00000	49.58711483
0.32498	0.00000	0.00000	0.00000	0.00000	47.85482497
1.00000	0.00000	0.00000	0.00000	0.00000	53.19472823
0.80000	0.00000	0.00000	0.00000	0.00000	50.6791587
0.59981	0.00000	0.00000	0.00000	0.00000	49.68654361
0.48279	0.00000	0.00000	0.00000	0.00000	43.36551881
0.78967	0.00000	0.00000	0.00000	0.00000	53.38875096
0.95497	0.00000	0.00000	0.00000	0.00000	54.1191158
0.80000	0.00000	0.00000	0.00000	0.00000	51.74078476
1.00000	0.00000	0.00000	0.00000	0.00000	53.32366802
0.97136	0.00000	0.00000	0.00000	0.00000	53.85530147
0.80000	0.00000	0.00000	0.00000	0.00000	50.5608459
0.63331	0.00000	0.00000	0.00000	0.00000	49.84156082
0.78960	0.00000	0.00000	0.00000	0.00000	47.29262156
0.45375	0.00000	0.00000	0.00000	0.00000	48.45688228
1.00000	0.00000	0.00000	0.00000	0.00000	55.78160755

performance and their sub factors' score. Further, BA can decide to eliminate those suppliers by setting a threshold number in each of the 5 categories or by factor, or by total score. In this case, BA's buyer or manager can easily rank their suppliers by different strategy purposes. Thirdly, according to those scores (by category or by total ranking score), BA may design the improvement plan for collaborating with suppliers to improve supply performance instead of simply eliminating them from the supplier list.

3.4 Proposed Improvement

The MPMFA approach has been proposed in previous section, and we have verified this method by the same datasets. Contrasting these two approaches, simple linear weighted (SLW) score ranking method is a linear model to assess suppliers' performance. However, MPMFA is a TQM based multivariate non-linear model. To assess supplier by MPMFA, it is crucial to find the optimal determinants of MPMFA function, that is, to find the maximal value $f(x)$ and the corresponding factors x (see the equitation 2).

$$\max_{x \in X} f(x) = Max: Ranking(P,F) = \sum_{i=1}^{5}\sum_{j=1}^{5} P_i F_j \,, \tag{2}$$

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Table 14. Comparison of SLW and MPMFA

Comparing the Simple Linear Weighted (SLW) Method with the Multi-Performance and Multi-Factor Assessment (MPMFA) Approach																				
Supplier ID	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Total Score by SLW	68.19	63.46	65.01	63.83	66.88	65.21	71.01	68.40	66.88	59.74	70.66	72.08	69.14	70.21	71.71	68.14	67.22	61.61	65.77	75.12
Rank by SLW	B	C	C	C	B	B	AA	A	B	C	B	AA	A	AA	B	B	B	C	B	AA
Total Score by MPMFA	50.84	47.58	48.49	46.67	49.59	47.85	53.19	50.68	49.69	43.37	53.39	54.12	51.74	53.32	53.86	50.56	49.84	47.29	48.46	55.78
Revenue by MPMFA	32.5048	33.2665	32.1806	32.1219	32.8261	32.2258	34.0557	32.2625	33.0675	32.1041	36.1693	35.2139	33.2514	35.4081	34.9805	32.2245	33.2030	32.4993	33.4765	37.3830
Service by MPMFA	5.4054	5.7364	5.7544	4.7613	5.9995	5.9313	5.5831	5.8340	5.8823	1.3929	5.7202	5.9273	5.9251	5.5493	5.7272	5.7658	5.6878	2.7565	5.9415	5.7143
Quality by MPMFA	5.1160	4.3412	4.5018	3.4948	4.4708	4.4788	5.4769	5.4776	4.4260	4.0480	4.4431	5.2599	5.4733	4.3831	5.3573	5.4785	4.5274	4.9889	3.3301	4.5000
Price by MPMFA	3.8894	3.8913	3.8911	3.8893	3.8908	3.9191	4.0791	3.9051	3.9116	3.8893	3.8974	3.8982	3.8910	3.9832	3.9049	3.8920	3.8901	3.8896	3.8937	4.1843
Organization by MPMFA	3.9200	0.3402	2.1634	2.4000	2.4000	1.2999	4.0000	3.2000	2.3992	1.9312	3.1587	3.8199	3.2000	4.0000	3.8854	3.2000	2.5333	3.1584	1.8150	4.0000

where, x stands for the set of factors might influence the ranking score.

For instance, Table 14 shows the results of comparing SLW method and MPMFA approach by using the same datasets. Although the original datasets are not enough to apply on MPMFA (proposed at the end of section 3.3), these results still demonstrate some important information that MPMFA is superior to SLW. For example, supplier 11 and supplier 14 have the approximate final ranking value which is 70.66 and 70.21 by using SLW method, and 53.39 and 53.32 by using MPMFA approach. However, their ranked supplier classes are different under SLW, that is, supplier 11 is ranked as class B, but supplier 14 is assigned to the best performance class as AA.

Why is there big difference of supply class even though suppliers have the approximate assessment numbers? Firstly, there is only a little difference with the final ranking scores by SLW and MPMFA, since these two approaches have been applied on the same datasets. However, it will be extremely different when all the data have been collected for MPMFA. From the result of applying MPMFA approach in Table 14, we can see supplier 11 needs to improve the organization performance such as increasing the credibility, serviceability and communication with BA, even though it has good revenue contribution for retailer. Secondly, the results of SLW ranking method can only determine the quantitative but not qualitative final assessment score and assigning a ranking class, however MPMFA approach shows more categorized detail information that might provide retailer to find the problems or issues that should be collaborated or cooperated with suppliers, instead of simply degrading or eliminating the supplier from the list. Therefore, with MPMFA approach, retailer might be more beneficial from the assessing results than SLW, that is, it is not only getting the quantitative assessment results, but also can find the qualitative factors to help suppliers improve the quality and performance.

In this process of supplier assessment and selection, summarized above example and the MPMFA approach in equation 1-2, it is not only we may find the max (or min) scores so as to rank suppliers, but also we can find the optimal determinants (x) and those factors ($\overline{x}$) that need to be improved. The linear weighted ranking score model only can identify those factors that contribute to the rankings of assessing suppliers, but it may not determine why those factors influence the suppliers' performance. Therefore, MPMFA approach is more efficient than linear weighted ranking score model.

Expanding the same example to demonstrate how to improve supplier 11's performance, according to the MPMFA assessment results, I propose a high level Hoshin Kanri strategy plan in figure 5. This Hoshin Kanri strategy plan is to ensure that the assessment of supplier selection should be conducted monthly by buyers, and also corresponding TQM action plans should have to be implemented so as

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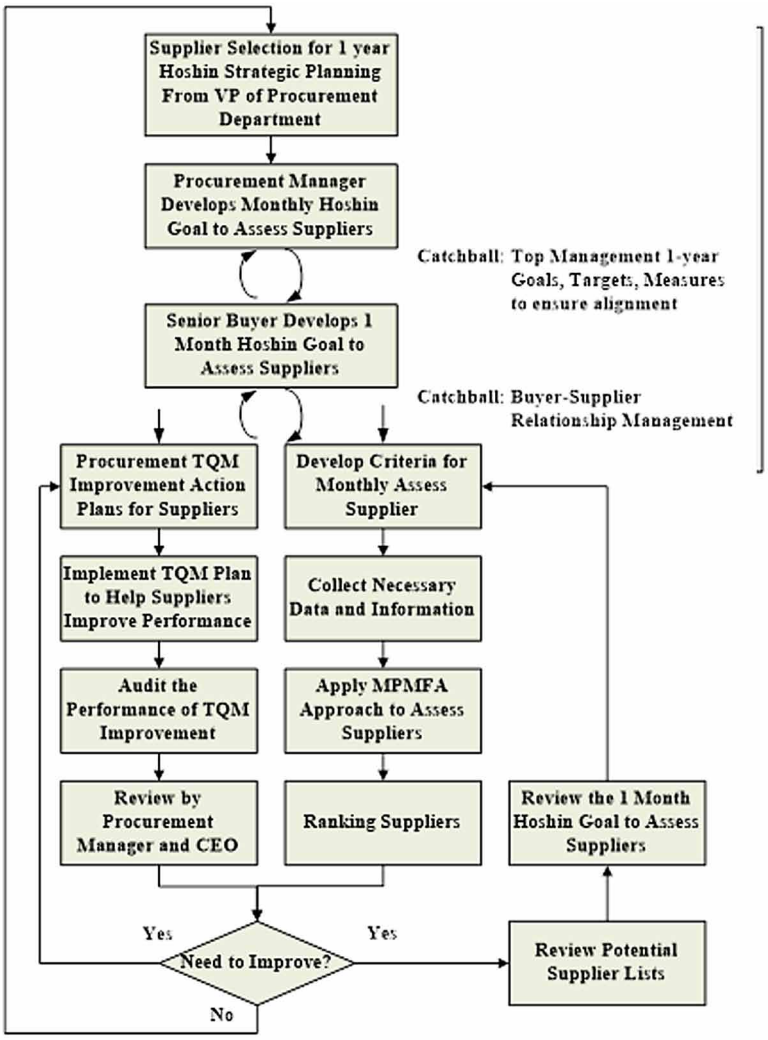
Figure 5. TQM based approach of a high level Hoshin Kanri improvement plan for senior purchasing manager



to help suppliers improve their performance and avoid risks among buyer-supplier relationship. This strategy may help buyers to establish the strategy partnership with suppliers so that the profits can be maximized and risks might be minimized for retailer.

To deploy this Hoshin Kanri plan, a corresponding operational plan should be developed, and it can be described as following:

1. Establish the Multi-Performance and Multi-Factor TQM based criteria to assess suppliers. Although we proposed 5 performances and many factors for each of them, it is not only limited for those. Hence, satisfying special requirements or focal strategies of evaluating suppliers, MPMFA might add more determinants as performance and factor criteria.

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2. According to the MPMFA criteria, retailer (or buyer) need to gather necessary data needed for assessing suppliers. Some of it may be collected by POS or IIS; however, some may need to be collected by surveys.
3. Conducting MPMFA approach in terms of the data collected.
4. Analyzing the results of scores, buyer can find either max score or min one. Whereas, those critical performance determinants and key factors influenced scores should have been identified, and then those problems need to be investigated, that is to find what are the causes lead a specific score, how is the severity of those problems, and how to solve those problems so as to improve the rankings.
5. Develop a strategic plan to select the supplier (who is maybe the first time to have business operation with retailer, or who is maybe already on potential supplier list.) or eliminate current suppliers who will not reach the standards, such as significant sales declination, bad product quality, low service level, financial crisis and so on.
6. Develop an operational plan to help those suppliers who have low scores, to reduce risks and solve the relative problems, since there are maybe the requirements of developing a strategy partnership with those suppliers.
7. Develop an audit plan to examine the results by helping improve suppliers' performances, and also need to establish a continuous improvement plan to sustain a stable buyer-supplier relationship.
8. This MPMFA approach should not only be implemented as needed, most importantly, but also it should have to periodically running to monitor retailers' business risks.

After designing the high level of Hoshin Kanri improvement strategy plan, we deploy this strategy to improve supplier 11's organization performance as Figure 6. In this figure, based on the MPMFA results and data collected, the senior purchasing manager will design a very detail operation plan in which supplier 11 should be requested to increase the business operation transparency and improve the efficiency of business communication, in order to improve the supplier relationship.

Accordingly, to implement this TQM based MPMFA approach, it may not isolate using the final scores to select or eliminate suppliers. This MPMFA method is a systematical methodology in order to reduce business risks, improve the business performance, develop a strategy partnership with suppliers, and also establish a green retail supply chain.

4. CONCLUSION

In the present paper, we reviewed risks in supply chain, especially in a retail industry. To tackle existing potential risks in supplier selection of procurement, we introduce the Total Quality Management method to identify and control risks. Correspondingly, a real case has been introduced by using a linear weighted ranking score method to assess suppliers. After analyzing the strengths and weaknesses of this linear weighted ranking score method, we proposed a TQM based multi-dimensional MPMFA approach to improve the quality of supplier selection. This multi dimension nonlinear method not only can improve the accuracy and efficiency of supplier selection, but also it may be useful for suppliers to improve their performance so as to develop a sustainable relationship between buyers and suppliers.

However, MPMFA is a conceptual model. Thereof, in this paper, there is a limitation to verify the performance of this approach. With this discussion and deep research applied on a real case, it is clear to find that MPMFA has developed a new perception to improve the quality of supplier selection. Thus,

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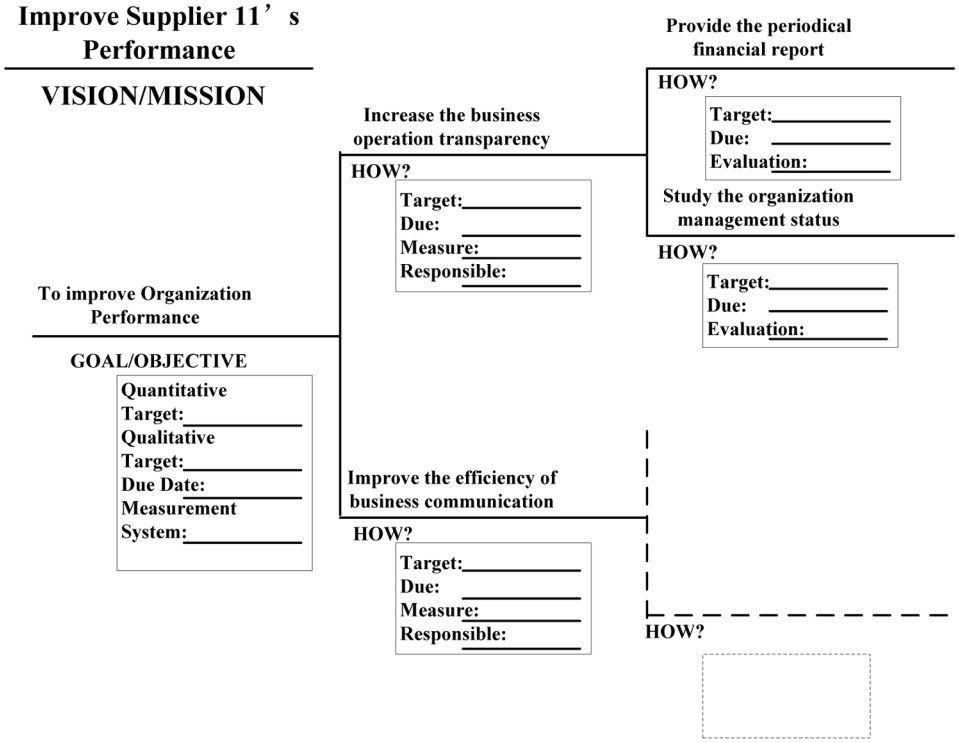
Figure 6. Detail Hoshin Kanri operation plan



in the future, we will continuously study this topic and help BA's buyers to conduct this approach so as to improve the efficiency of assessing and selecting suppliers.

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Chapter 20
A Comprehensive Review on Advanced Maintenance Strategies for Smart Railways

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ABSTRACT

Recently, energy efficient and sustainable supply chain has attracted a great deal of attention. To achieve sustainability, it is of paramount importance to use environmentally friendly procedures in each stage of the supply chain including suppliers, production/manufacturing, and transportation. Transportation plays a critical role in supply chain since the suppliers and customers are typically distributed in large geographical areas. Nowadays, railway is considered as a primary mode of transportation. Railways are considered as complex systems that are subject to degradation and failures. To avoid failures, tremendous efforts should be invested on preventive maintenance (PM) for performing optimal maintenance actions. Proper PM actions such as condition-based maintenance (CBM) play a major role in keeping the supply chain from crumbling down and working with high efficiency. This chapter reviews promising research works in the application of state-of-the-art CBM strategies that contribute to the advancement of smart transportation system via fault diagnostics/prognostics.

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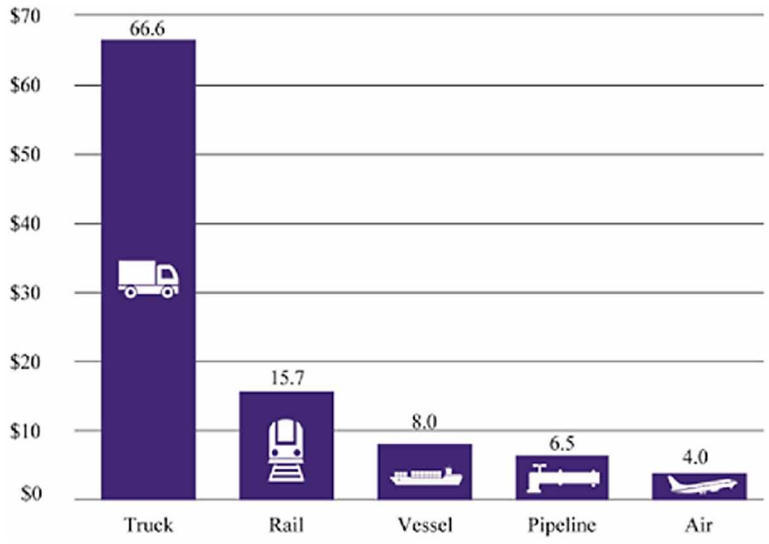
Figure 1. North American freight by mode of transportation ("Bureau of Transportation Statistics," n.d.)



INTRODUCTION

It is widely accepted that transportation plays an undeniably critical role for uneventful operation of supply chain networks. Considering the fact that transportation is one of the main sources of environmental pollution within the supply chains (Wu & Dunn, 1995), it is significantly important that the transportation logistics and planning agencies devise innovative, economic and environmentally friendly transportation solutions. Although trucking remains the major and dominant mode of freight transportation due to its high accessibility, shifting freight away from trucks is more appealing from economic and environmental points of views considering the desire to reduce the overall carbon emissions. Potential shift to more efficient and safe modes of transportation such as trains addresses the issues related to increasing costs associated with maintenance of highway infrastructure, pavement damage, the cost of fuel, and specially carbon emission. Therefore, nowadays railways are considered as the dominant and popular alternative mode of transportation to trucking. For instance, in the United States ("Bureau of Transportation Statistics," n.d.), railways are one of the major modes of freight transportation constituting the largest network within any single country at 140,000 miles of Class 1 tracks. The network is predominantly focused on freight traffic with the exception of key passenger corridors along the eastern seaboard and in the upper Midwest. According to recent North American freight statistic shown in Figure 1, railways are the second largest mode of transportation after trucking, moving $150 billion or 14.5 percent of imports and exports during January 2018 to October 2018. Such statistics, therefore, increase the pressure on railways to maintain a high level of quality service during their operation.

Railway networks (RWN) consist of multiple complex mechanical and electrical systems with hundreds of thousands of moving parts. The embedded components and equipment deteriorate over time since they are operating under certain stress or load in the real environment. In order to make the railway systems more reliable and safer, the railway network must be monitored and maintained continuously over time. If proper maintenance actions are not taken into consideration in due time within the operation of railway transportation systems, catastrophic failures could occur leading to a variety of severe

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consequences ranging from delays in delivery, customers dissatisfaction, destruction of infrastructures to endangering human lives. One of the major components in the railway industry is the "railway track" which is crucially prone to degradation and failure. It was reported in 2009 (F. Peng, Kang, Li, & Ouyang, 2011) that 658 train accidents out of 1,890 were due to track defects. In order to mitigate such failures, the railway companies in North America spend billions of dollars on rail network maintenance to increase the overall reliability and safety of the networks (Peng et al., 2011).

In general, maintenance techniques can be categorized into two main groups: (i) Unplanned maintenance actions, and; (ii) Planned maintenance. The former category is considered as the most basic maintenance technique, which is also known as breakdown maintenance, corrective maintenance or run-to-failure maintenance. In this strategy, maintenance is performed only at failure (breakdown) times. The second maintenance technique, i.e., planned maintenance, is commonly known as preventive maintenance (PM). Traditional PM models can be classified into the following main categories: (i) Age-based replacement models; and; (ii) Block replacement models. Such traditional models are simple and easy to implement; however, they do not take into account the information obtained from condition monitoring (CM), which results in inaccurate failure predictions and sub-optimal maintenance cost (K.S.Jardine, Lin, & Banjevic, 2006). The state-of-the-art maintenance program is known as condition-based maintenance (CBM), which uses the collected set of CM data to determine the optimal times to preventively repair/replace the system. In the CBM, the maintenance actions are performed only when the observed data indicate severe system deterioration. When applying CBM, the average cost is significantly reduced by eliminating the unnecessary maintenance operations. Recent surge of interest in smart manufacturing has resulted in simultaneous incorporation of several advanced monitoring technologies such as Internet of Things (IoT) and Wireless Sensor Networks (WSN) (Hodge, Keefe, Weeks, & Moulds, 2015) within CBM domain, which are inherent in Industry 4.0 and are fueled by exponential growth of CM data reshaping the landscape of transportation systems. This trend is clearly visible in the railway sector. Track owners are implementing advanced monitoring technologies and smart systems to monitor the health condition of tracks during normal operations for performing optimal or near-optimal maintenance decision making.

Recently, railway industries deploy automated vision-based wayside inspection systems for monitoring rail infrastructure and trains to facilitate management of rail transport assets for achieving high availability and reliability. Different non-contact and remote advanced measurement technologies have been developed for smart railway transportation. These products are particularly designed to collect relevant information to effectively monitor railcar components and train infrastructure health conditions resulting in availability of high volume, high variety, and high velocity CM data. Utilization of such CM data increases the complexity of CBM within transportation systems, rendering conventional monitoring techniques impractical. This has resulted in increasing the interest for applying more advanced monitoring techniques such as machine learning and big data analytics in this context (Jamshidi et al., 2018). It is, therefore, vital and of great practical importance and theoretical significance to develop an advanced health monitoring/management system in the railway industry via the utilization of ever-increasing CM data by devising innovative processing, learning, and big-data analytic solutions. In brief, such an advanced monitoring and energy efficient system in place should be able to: Extract relevant and useful information of the transportation system in real time; cooperatively estimate the underlying state of the system based on CM data in intelligent and intuitive ways, and construct optimal maintenance policies for decision-making. In summary, the common theme of this book chapter is to review and investigate promising research ideas in the application of state-of-the-art CBM that contribute to the advancement of energy efficient transportation systems via fault diagnostics/prognostics of railway infrastructures and trains.

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The remaining sections of the chapter are organized as follows: Section of maintenance strategies in RWN, briefly reviews different PM strategies and data acquisition solutions to accomplish diagnostics and prognostics. Then, models and methods for data processing that are essential for diagnostics and prognostics are reviewed in data processing section. Section of maintenance decision making provides and overview on the key ideas and methodologies for maintenance decision-making, the final step to accomplish diagnostics and prognostics. Finally, last section concludes the chapter and addresses research directions needed for the development of next generation of diagnostic/prognostic systems and possible future development trends of diagnostics and prognostics.

BACKGROUND

There has been a recent surge of interest, amongst different research communities, on maintenance of RWNs. The RWN is considered as a complex system consisting of thousands of parts and components. In general, components which are subject to degradation in railway transportation system can be categorized into three groups, namely: (i) Infrastructure; (ii) Vehicle, and; (iii) Signaling sub-systems. Infrastructure defects include track defects and track subgrade defects. Track defects being studied in the literature include track geometry defects, track surface defects and track fastening components defects. Vehicle components defects mostly being studied in CBM context include train wheels, bogies, bearings, and braking system. Distribution of different railway components subject to monitoring and maintenance in reviewed papers are shown in Table 1. It can be observed that the majority of open literature on monitoring and PM contexts in RWN is devoted to track and vehicle monitoring, while the signaling sub-systems are overlooked. Considering different types of available maintenance strategies, the focus of published articles on maintenance of RWNs context is mainly targeted on PM techniques. In particular, the focus was mainly on traditional PM strategies. Reference (Ghofrani, He, Goverde, & Liu, 2018) provides a recent review on such traditional techniques applied for maintenance of RWN. In the next section, this chapter presents a general overview of the application of the state-of-the-art CBM, in RWNs. For this purpose, after introducing different condition monitoring systems in RWNs, a comprehensive study on application of machine learning algorithms including both shallow structure techniques and deep learning algorithms in CBM context in RWNs is presented.

CONDITION-BASED MAINTENANCE (CBM) IN RWNs

CBM is the state-of-the art maintenance strategy that utilizes CM data in order to detect an existing fault or predict a fault before it happens in a system subject to degradation. In the CBM strategy, maintenance actions are only performed when there is an evidence of severe system degradation leading to significant reduction in maintenance cost and downtime. The CBM strategy consists of three main steps: (i) Data acquisition; (ii) Data processing, and; (iii) Maintenance decision-making (K.S.Jardine et al., 2006). In the following, each step is discussed in detail.

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Table 1. Distribution of the reviewed papers by the railway components subjected to degradation

Category	Component Subject to Degradation	Related Articles
Infrastructure	Track geometry	(Sharma, Cui, He, Mohammadi, & Li, 2018), (He, Li, Bhattacharjya, Parikh, & Hampapur, 2017), (Zarembski, Einbinder, & Attoh-okine, 2016), (António Ramos Andrade & Teixeira, 2012), (Chiachío, Chiachío, Prescott, & Andrews, 2019), (Cárdenas-gallo, Sarmiento, Morales, Bolivar, & Akhavan-Tabatabaei, 2016), (Lasisi & Attoh-okine, 2018), (Rhayma, Bressolette, Breul, Fogli, & Saussine, 2013), (A R Andrade & Teixeira, 2015)
	Track surface	(Núñez, Hendriks, Li, Schutter, & Dollevoet, 2014), (Wei, Núñez, Li, & Dollevoet, 2017), (Giben, Patel, & Chellappa, 2015), (Jamshidi et al., 2018), (Molodova, Li, Núñez, & Dollevoet, 2014), (Zhuang, Wang, Zhang, & Tsui, 2018), (M. P. Papaelias & Lugg, 2012), (Núñez, Jamshidi, & Wang, 2019), (W. Chen et al., 2018)
	Track fastening components	(Y. Li, Trinh, Haas, Otto, & Pankanti, 2014)
	Track subgrade	(Xu, Lei, & Yang, 2018), (Du, Liao, & Yang, 2010)
Vehicle	Bearing	(Fumeo, Oneto, & Anguita, 2015), (Peters, 2017), (Yi, Lin, Zhang, & Ding, 2015), (Vale et al., 2016), (Amini, Entezami, & Papaelias, 2016), (X. Zhao & Jia, 2018), (Jiang, Li, Shao, & Zhao, 2018), (S. Zhang, Zhang, Wang, & Habetler, 2019), (M. Papaelias, Amini, & Huang, 2016) (D. Peng, Liu, Wang, Qin, & Jia, 2019)
	Wheel	(M. Papaelias et al., 2016), (H. Li et al., 2014),, (Z. Li & He, 2015), (Hajibabai et al., 2012), (W. Wang, He, Cui, & Li, 2018)
	Bogie	(Rao, Yang, & Jiang, 2019), (Kou, Qin, Zhao, & Fu, 2019), (Hu, Tang, Gong, Wei, & Wang, 2017), (Y. Zhao, Guo, & Yan, 2017)
	Braking system	(J. Liu & Zio, 2018), (Jie Liu & Zio, 2018)
Signaling Systems		(G. Wang, Xu, Tang, Yuan, & Wang, 2017), (Dindar, Kaewunruen, An, & Sussman, 2018), (Sysyn, Gruen, Gerber, Nabochenko, & Kovalchuk, 2019)

Data Acquisition

Data collected for CBM purposes in RWNs can be either "*Event Data,*" which is a manually-recorded history of what happened for the system over its lifetime or "*Condition Monitoring (CM) Data*," which is measuring some parameters periodically or continuously in order to monitor and interpret the current status of the system (K.S.Jardine et al., 2006). The CM data acquisition process itself contains three main parts: (i) Data collection; (ii) Data communication, and; (iii) Data storage. Furthermore, CM data is commonly collected with different types of sensors mounted on board attached to the components needed to be monitored or embedded within the target component. Data collected by sensors is then communicated to a base station via wired connections or via wireless transmission protocols such as Bluetooth or Wi-Fi. The base station transmits the collected data to a control center server, referred to as the Fusion Centre (FC), through satellite or General Packet Radio Services (GPRS). Finally, the control server will transfer the collected data to a database for data storage (Hodge et al., 2015).

There are different types of CM data specific to railway transportation systems including, but not limited to, acoustic data, vibration data, temperature, pressure, images/video sequences, and weather or environment data. Different types of sensors and CM systems should be used based on the type of data collected and the component under monitoring. Next, we introduce different types of CM systems applicable for a railway transportation system.

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Step 1: Data Acquisition via Railway CM/Inspection Systems

During recent decades, CM and inspection technologies, which facilitate CM data acquisition, have become an important part of the railway industry. Recently, advanced non-contact, automated vision-based wayside and remote inspections systems are deployed in smart railway industries to effectively monitor and inspect health condition of the railcar and track infrastructure components. This section provides an overview of innovative products designed to provide valuable CM data for railcar components and track and ensuring conditions for their safe operation. In general, most common track CM/inspection systems can be classified into two groups:

1. Railway subgrade inspection systems, and
2. Vehicle-mounted track inspection systems.

On the other hand, most common railcar CM/inspection systems (referred to as wayside inspection systems) can be classified into two general groups:

1. Reactive wayside inspection systems, and
2. Preventive wayside inspection systems.

Next, we further present details of the above-mentioned inspection technologies.

Railway Subgrade Inspection System

Railway subgrade defect (Xu et al., 2018) is a serious safety threat in railway transportation systems. The most widely used defect detection equipment of railway subgrade is the vehicle-mounted ground penetrating radar (GPR). Using high-frequency electromagnetic waves, the GPR system investigates the distribution of subsurface media. The constituent components of a GPR system is shown in Figure 2. In a

Figure 2. Ground penetrating radar in railway subgrade defect detection (Xu et al., 2018)

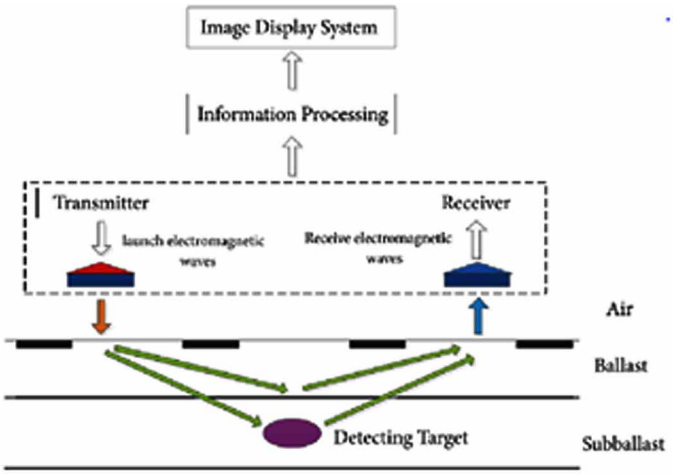

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Figure 3. Subgrade CM vehicle equipped with GPR technology (Chiachío et al., 2019)

Figure 4. ABA measuring train and a close view of accelerometer (Wei et al., 2017)

GPR system, high-frequency electromagnetic waves are emitted from the transmitter; therefore, the receiver receives the reflected electromagnetic waves and the host radar saves their motion characteristics into the internal database. Then, the visualization (image display) system generates the cross-sectional image of the subsurface layers. A subgrade CM vehicle equipped with GPR technology is shown in Figure 3.

Vehicle-Mounted Track Inspection System

One widely used track CM and inspection technology is Axle Box Accelerometer (ABA) (Wei et al., 2017). Accelerometers are mounted on the axle boxes to capture track irregularities. At the same time, the GPS antenna records the location of the defects (Figure 4). Any irregularities, including track surface defects or track geometrical issues, will cause a significant change in vehicle-track interaction, which can easily be captured through changes in the ABA signals. Due to its ability in detecting track defects, the ABA data has been widely used in the literature for making railway CBM decisions.

Wayside Track Inspection Systems

Advanced CM and inspection technologies are developed in RWN industries to monitor the train components, referred to as the wayside inspection systems. Wayside CM systems are located near or adjacent

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Figure 5. (a) Hot bearing detector (HBD). (b) Dragging Equipment Detector (DED) (Schlake, 2010)

to the tracks. These devices are typically used to monitor and inspect the vehicle component subject to different failures such as wheels, brake systems, bogies and bearings. Different types of sensing technologies have been implemented in wayside monitoring systems to measure heat, force, visual parameters and sound (Schlake, 2010). Some wayside detection systems can be considered as reactive inspection systems since they require a train to stop to be repaired if a serious problem is detected. These technologies are applicable only for the purpose of corrective maintenance because they are able to detect the defect shortly before or even after failure has occurred causing many in-service failures each year. An example of reactive inspection systems is Hot Bearing Detectors (HBDs), which are installed adjacent to the track and are able to recognize overheated journal bearings using infrared sensors (Figure 5(a)). Dragging Equipment Detector (DED) (Schlake, 2010) is another reactive inspection system. Using a vertically positioned metal board inside the gage of the track and attached to an electronic sensor, DED can detect low hanging equipment (Figure 5(b)). In the case that a serious defect is detected, radio-based alarm is used to inform the train crew.

Recently, different wayside inspection systems and technologies are designed to monitor the condition of truck components over time. These systems provide information required for performing preventive and CBM actions. Based on the underlying component subject to CM, most common wayside CM/ inspection systems can be categorized into different groups including but not limited to:

- **Acoustic Bearing Detector (ABD):** It can detect the roller bearing defects by analyzing the frequency of generated noises from bearing (APNA_GROUP, n.d.) (Figure 6(a)).
- **Wheel impact load detectors (WILD):** It is the most widely used inspection system in the world that measures impact forces caused by damaged wheels ("L.B. Foster Company," n.d.) (Figure 6(b)).
- **Truck performance detector (TPD):** This inspection system consists of a series of strain gauge sensors that are located besides the track to measure forces during the negotiation curves ("International Electronic Machines Corporation," n.d.) (Figure 6(c)).
- **Full automated train scanning system (FATSS):** It is a full scale train imaging and 3D scanning inspection system that provides image data corresponding to all externally visible components of a rail vehicle ("Trimble Beena Vision Solutions," n.d.) (Figure 6(d)).
- **Wheel view inspection system (WVIS):** The wayside wheel profile inspection systems are designed to inspect wheels for recommending PM strategies. The CM data including but not limited to flange height, flange width, flange slope and full wheel profile are measured at high speed of up to 140 km/h via this technology ("Trimble Beena Vision Solutions," n.d.) (Figure 7(a)).

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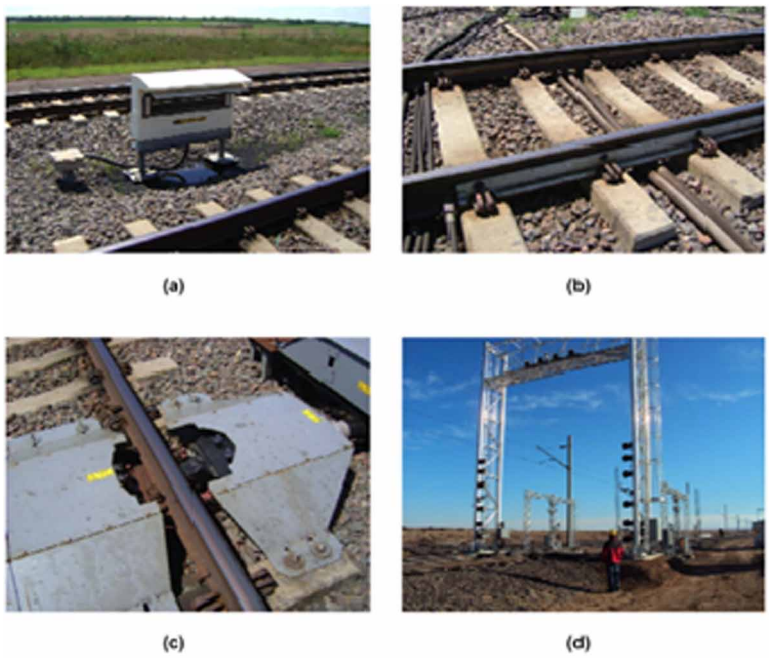
Figure 6. Automatic condition monitoring technologies: (a) ABD. (b) WILD. (c) WPD. (d) FATSS (Hajibabai et al., 2012)



- **Wheel tread inspection system (WTIS):** This technology is a non-contact wheel surface inspection product, which uses optical imaging and 3D laser scanning to inspect wheel tread surface, flange and plate areas in order to detect any surface abnormality in a wheel. This technology is capable of inspecting and measuring different defects such as broken wheel sections, and broken flanges ("Trimble Beena Vision Solutions," n.d.) (Figure 7(b)). The CM data collected through this technology is a set of images as shown in Figure 7(c).
- **Brake view inspection system (BVIS):** This technology is designed in order to acquire digital images of brake disc for inspection purposes ("Trimble Beena Vision Solutions," n.d.) (Figure 8).
- **Bogie inspection system (BIS):** This inspection system is designed to inspect and measure different features of bogies including fasteners, side frame condition, bearings and related components, friction wedges, springs, and more. Alarms are generated when issues are detected ("Trimble Beena Vision Solutions," n.d.) (Figure 9).

Figure 7. (a) WVIS. (b) WTIS. (c)Image type CM data for wheel surface ("Trimble Beena Vision Solutions," n.d.)

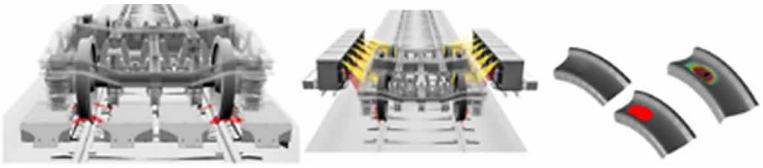


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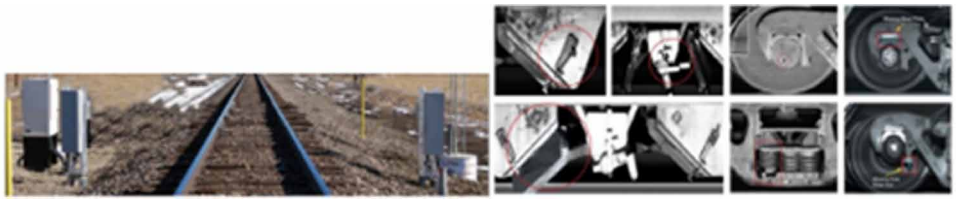
Figure 8. BVIS ("Trimble Beena Vision Solutions," n.d.)

Figure 9. BIS ("Trimble Beena Vision Solutions," n.d.)



Steps 2 and 3: Data Communication and Storage via Wireless Sensor Networks

As stated previously, the CM data are collected via various CM/inspection technologies/sensors where each sensor measures specific property of the underlying component subject to CM. In a conventional and simple CM, when a sensor reaches a predetermined threshold, an alarm will be sent to rail crew in order to take the proper action. Although this approach is simple and easy to implement, it may lead to a large number of false alarms and missed failures due to locally processing CM data (J. Chen & Roberts, 2006). In order to address such shortcoming, not only these sensors should observe the underlying system independently and process the CM data locally, they should collectively collaborate, which challenges the conventional CM vision and necessitates development of wireless sensor networks in RWNs for CBM purpose. Figure 10illustrates a typical wireless network system for railway (Hodge et al., 2015). The CM data collected by sensors is communicated to a base station by the help of a wireless transmission protocol. The base station transmits the collected data to control center server through satellite or GPRS. Then, the control server will transfer the collected data to a database for data storage. Integrated data processing provides an overall picture of the system's condition and monitors the overall trend of railway condition, consequently, the number of missing failures or false alarms will considerably be decreased.

It is worth mentioning that when multiple sensors are used, data collected from different sensors has different types and contain different partial information about the same system's condition. The key problem here is how to combine all partial information obtained from different sensors for more accurate system diagnosis and prognosis. Thus, with a large amount of multi-sensory data available, data fusion techniques should be employed. Please refer to recent publications for further details on data

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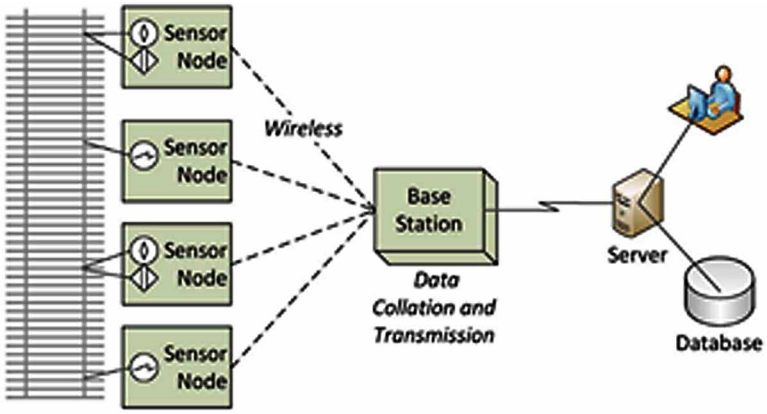
Figure 10. A typical wireless network setup for railway CBM (Hodge et al., 2015)



fusion in RWNs provided in (Lederman, Chen, Garrett, Kovac, & Bielak, 2017), (Zuo, Ding, Hu, Han, & Zhang, 2019). Another problem/challenge originates from sensors is that data collected via remote monitoring sensors could contain errors caused by humans or sensor itself. Sensor itself is subject to stochastic degradation, which leads to occurrence of random faults. Due to the large number of sensors installed in RWNs, the probability of sensor faults increases naturally, which will result in communicating false CM data to the processing node. If sensor inaccuracies are ignored and left untreated, system performance will be affected. For accurate diagnostics and prognostics in CBM context, therefore, we need to incorporate the sensor faults into the system model. Sensor faults can be classified into several categories such as complete failure, mean bias or drift, and deteriorations. The complete failure is easy to detect because the sensor is no longer capable of providing monitoring data, however, other sensor fault types are generally much harder to detect. Most existing research on sensor faults (K. Zhang, Jiang, Yan, & Mao, 2016) deals with the sensor drift, while research on the fault coming from degradation of the sensor within the CBM context is still in its infancy.

Data Processing

Data processing is the second and most important step of a CBM strategy. Data processing is the process of transforming raw sensory data into useful and practical information, which can help maintenance decision-makers to select the most cost-effective and reliable maintenance policy.

In general, there are two types of data processing techniques for CM:

1. Statistical Approaches: In statistical approaches, the behavior of the system is modeled based on the behavior of each individual component that needs very detailed knowledge about the system that is very difficult to be obtained. References on statistical approaches on fault diagnostic and prognostic are provided in (Bjarne Bergquist & Söderholm, 2015) and (B. Bergquist & Söderholm, 2014).
2. Data-driven Methodologies: Data-driven approaches (Arnaz Malhi, Yan, & Gao, 2011) are performed based on analysis of previously (historical) fault and healthy data and predicting the status of a system based on measurement data during system operation.

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As mentioned previously, recent surge of interest in smart RWNs has resulted in simultaneous incorporation of several advanced monitoring/inspection technologies and are fueled by availability of high-dimensional and multi-modal streaming (HDMS) CM data. In general, CM data collected via various sensors in RWNs can be categorized into three main groups:

1. Single value type data such as temperature or pressure;
2. Waveform type data such vibration signals or any other kind of time-series data and finally,
3. High-dimensional type data such as visual images.

The complex characteristics of the HDMS data sources such as high variety, high dimensionality, high velocity, and complex spatial/temporal structure pose significant analytical challenges, rendering conventional statistical approaches impractical. Consequently, there has been a significant recent surge of interest in Machine Learning (ML) based solutions in fault diagnostics and prognostics.

Similar to digitalization, which transformed end-to-end business models, the artificial intelligent (AI) and ML are positioning themselves as the transformative technologies of the century leaving the industries with two options: "Embrace the system monitoring via AI/ML solutions or get left behind". Applications of AI/ML techniques are no longer just "good to have" - in near future they will soon be business critical, as such are the main focuses of the proposed book chapter. The driving key factor that increasingly empowers this hype and posed to reshape the competitive landscape of the smart RWNs is exponential growth of HDMS CM data. Conventional ML based solution consist of the following key steps:

1. Handcrafted feature design;
2. Feature extraction/selection, and;
3. Predictive classification/regression model construction.

In waveform CM data such as vibration signal, which is the most common waveform data for CM purpose in RWNs, feature extraction techniques are widely applied. The selection of appropriate feature extraction technique in a way that keeps the most useful information and achieves the highest accuracy in data analysis needs the expert knowledge of the domain. Feature extraction can be done either in time-domain, frequency domain or time-frequency domain. Waveform data are usually recorded in time domain. In time-domain analysis, a continuously recorded time signal is divided into smaller windows with proper lengths and then descriptive statistics such as mean, peak, standard deviation, root mean square, skewness and kurtosis are obtained for each window intervals. These calculated statistics are called time-domain features and contain the most possible information of the original signals (K.S.Jardine et al., 2006). Time-domain analysis is a useful approach in machinery fault diagnostics ((W. Chen et al., 2018), (H. Li et al., 2014)). In frequency-domain analysis, the time-series signals are transformed into frequency domain. Fast Fourier transform (FFT) in spectrum analysis is the most widely used technique for this transformation. The advantageous of frequency domain analysis over its time-domain counterpart is the ability to easily recognize and isolate certain frequency components of interest. Time-frequency analysis is usually used when signal's behavior is non-stationary, a common phenomenon in the CBM context. Short-time Fourier transform, Wigner–Ville distribution, and wavelet transforms are the most commonly used time-frequency distributions in the literature (K.S.Jardine et al., 2006). More recent references in this line of research in RWNs are given by (Molodova et al., 2014), (Yi et al., 2015), (Amini et al., 2016), (M. Papaelias et al., 2016), (Rao et al., 2019).

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The researches conducted on CM and maintenance optimization areas considering high-dimensional data such as images and video sequences, mostly applied image processing techniques such as feature extraction and dimensionality reduction techniques for diagnostics/prognostics ((Dong, He, & Banerjee, 2006), (Xiang, Coit, & Feng, 2014)). To name a few, they usually apply wavelet transform, Low-Rank Tensor Decomposition and (log)-location-scale regression model, into raw images for fault diagnosis and prognosis. Then, some shallow algorithms are mostly applied for fault detection and classification. It is worth mentioning that diagnostic problems in majority of cases in the CBM context can be considered as a classification problems. In what follows, we briefly overview the most applicable traditional classification algorithms that have been used for railway CBM decision making.

Support Vector Machines (SVM)

Support vector machine (SVM) is a classification model, which has been originally designed for binary-class classification problems (Cortes & Vapnik, 1995). However, by applying some voting techniques such as one-vs-one or one-vs-all, it can be easily adjusted for multi-class classification. The SVM has been widely used for railway fault detection. A recent work applying SVM for identifying train wheelset faults can be found in (H. Li et al., 2014), where the results of classification by SVM outperforms other classification techniques. Another example of the SVM application in railway CBM can be found in (W. Chen et al., 2018), where frequency-domain features extracted from magnetic flux leakage signals have been classified using SVM model for rail crack recognition. The SVM technique can also be used for detection of track geometry defects (Cárdenas-gallo et al., 2016), (Lasisi & Attoh-okine, 2018), and detecting train braking system defects (J. Liu & Zio, 2018).

K-Nearest Neighbors (k-NN)

K-nearest neighbors algorithm (*K*-NN) is a classification technique which assigns an object to the class of the most similar neighbor between k nearest neighbors. The similarity is determined based on Euclidean distance and the algorithm output is the class membership of the objects. Recent publication on application of *K*-NN technique is presented by (J. Liu & Zio, 2018) where a K-NN-based fuzzy SVM is proposed in order to detect bearing faults in high speed trains. More references in bearing fault detection via K-NN approach can be found in (A. Malhi & Gao, 2004) and (Tian, Morillo, Azarian, & Pecht, 2016).

Decision Tree (D3)

Decision tree (D3) is a classification algorithm which tries to solve the problem by constructing a decision tree. In a decision tree, each internal node represent an attribute and each leaf node is related to a class label. As an example, the authors in (Peters, 2017) constructed a D3 based on temperature deviations to detect train axel bearing failures one to three months earlier. More references in this line of the research can be found in ((Rodriguez-galiano, Ghimire, Rogan, Chica-olmo, & Rigol-sanchez, 2012), (Elangovan, Devasenapati, Sakthivel, & Ramachandran, 2011), (Santur, Karaköse, & Akın, 2017), (Dai, Liu, Hu, & Huang, 2016)).

Convectional ML-based solutions are conducted, typically, based on feature extraction/selection. It is, however, difficult to determine the appropriate kind of features for a complex domain. At the same time, design of feature extraction/selection methodologies is another tricky problem. At last, the above-

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mentioned three modules cannot be jointly optimized, which may hinder the final performance of the whole system. These drawbacks of conventional ML solutions are mainly attributed to their shallow architecture (Hinton, Osindero, & Teh, 2006). It is shown (Bengio, Courville, & Vincent, 2013) that the representation defines the upper-bound on achievable performances of ML algorithms. Consequently, there has been a significant recent surge of interest in deep learning based solutions, which aim at extracting hierarchical representations from input data by building networks with multiple layers of non-linear transformations. In fact, deep learning is not a new idea, the popularity of deep learning today can be contributed to increasing computational power; availability of HDMS data (Baltrušaitis, Ahuja, & Morency, 2017), which can offset the increased complexity behind deep learning (S. Yin, Li, Gao, & Kaynak, 2015), and; advanced deep learning research, which has significantly emerged since 2016. Considering the extraordinary power of deep learning to handle high-dimensional data and to learn high-level representation make it a powerful and effective solution for system health monitoring ((R. Zhao et al., 2019), (Bai et al., 2018)). Deep learning-based solutions offer the following exceptional benefits for diagnostics and prognostic tasks in modern complex systems such as RWNs:

- Provide end-to-end system, which can automatically learn internal representations from raw input;
- Do not require extensive human labor and knowledge for handcrafted feature design;
- All model parameters including feature module and pattern classification/regression module can be optimized jointly, and;
- Flexibility in the sense of transfer learning where trained models for fault diagnosis problem can be used for prognosis by proper calibration.

Nowadays, deep learning techniques are getting more popular in the CBM context. Recent review on application of different deep learning techniques for bearing fault diagnostics is presented by (S. Zhang et al., 2019). Applications of deep learning techniques in predictive maintenance, although being significantly challenging, has the great potential to introduce exceptional benefits such as superior availability and reliability of assets, reduced capital expenditure (fleet size can be decreased with improved asset availability), and reduced operational expense (e.g., replacement costs). Next, the most popular deep learning algorithms, i.e., Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN), which are widely applied in RWNs for CBM purposes are discussed in detail.

Convolutional Neural Network (CNN)

CNNs showed great performance in different computer vision applications when they are fed with 2 or 3 dimensional input data. The representation of CNN architecture has been presented in Figure 11. This algorithm is trained to recognize images by detecting visual features from an image, through convolution layers in a hierarchical way. In the area of image recognition, CNN classification results, as a feature-learning based approach, have significantly outperform the conventional ML algorithms developed based on artificial feature extraction. Recently, there has been an increasing surge of interest on applying CNN for CM purpose in RWNs. CNN is successfully applied in RWNs to automate track inspection (Giben et al., 2015) such that a fully-convolutional deep CNN architecture is proposed to localize and inspect the condition of railway components. The input of the model is a set of high resolution track bed images. The results show the great performance of CNN to capture more complex patterns in grey scale images. Application of CNN in railway surface defects diagnostic is given by (Jamshidi et al., 2018). A recent

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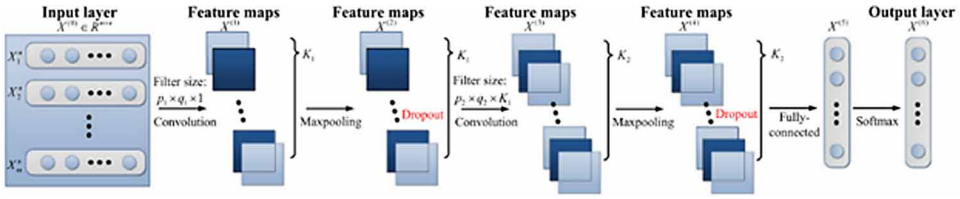
Figure 11. CNN architecture (S. Zhang et al., 2019)

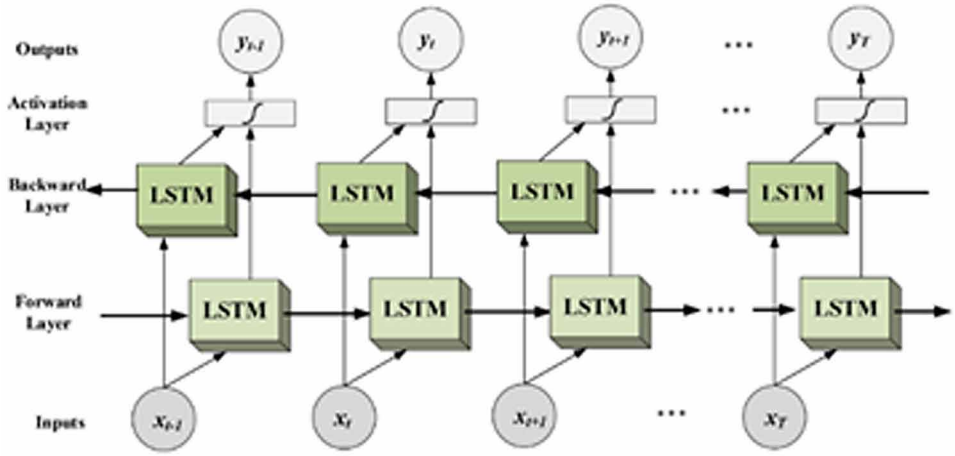


reference focusing on application of CNN for subgrade defect recognition is provided by (Xu et al., 2018). Although CNN is well known for its great capability in detection of abnormalities in 2D and 3D CM data, one dimensional CNN which uses one dimensional filter can be used for waveform data analysis. In (Liang et al., 2018), one dimensional CNN has been applied for fault diagnosis of high-speed train bogie.

Recurrent Neural Network (RNN)

RNN is a well-performed neural network technique, which has been developed for classification of sequential data, i.e., waveform type CM data such as vibration signals. RNNs are commonly used for analysis of any kind of sequential data like video processing, signal processing, text mining and sentiment analysis, natural language processing and speech recognition (Auli, Galley, Quirk, & Zweig, 2013). RNNs can be learned by backpropagation over time during a supervised learning process. An early application of RNN on bearing fault detection can be found in (Abed, Sharma, & Motwani, 2015). The main drawback of RNN is the exploding or vanishing gradients during training phase which may cause increasing the error or degrading the earlier information over time steps. Consequently, Long-Short Term Memory networks (LSTMs) were developed which is a member of RNN family that is capable of capturing long-term dependencies in time series data. LSTMs can solve the vanishing/exploding gradients problem by the help of retain and forget gates which retain relevant information and forget irrelevant information, respectively (Goodfellow, Bengio, & Courville, 2016). Bidirectional LSTM network is proposed by (Graves, Mohamed, & Hinton, 2013). While the LSTM layers look at the sequential data

Figure 12. Bidirectional LSTM network structure (Yildirim, 2018)



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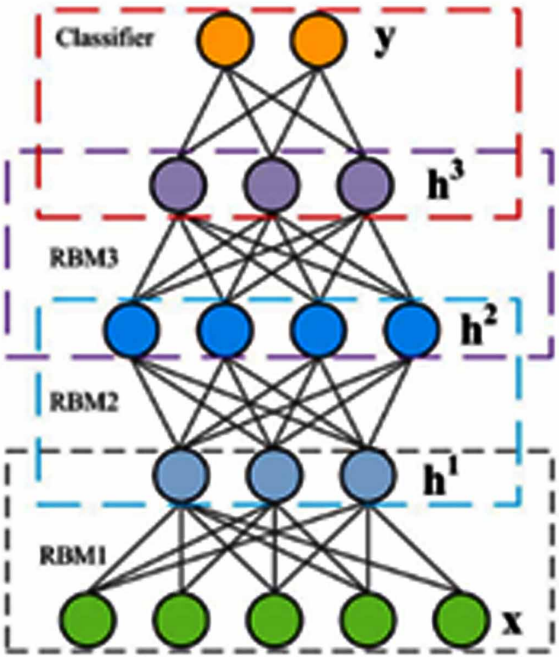
in the forward direction, a bidirectional LSTM layer can take into account the sequence data in both forward and backward directions (Schuster & Paliwal, 1997). A sample structure of bidirectional LSTM network has been shown in Figure 12.

Application of the LSTM networks in fault bearing detection can be found in (Guo, Li, Jia, Lei, & Lin, 2017). Recently, application of LSTM networks for rail crack detection is presented by (X. Zhang et al., 2018). Simulated acoustic emission signals are considered as an input of the proposed LSTM network. Another study published recently on application of LSTM network on railway track circuit fault diagnostic is (Bruin, Verbert, & Babuˇska, 2017). LSTM based temperature prediction for hot-axles of locomotives is given by (Luo, Yang, Huang, & Deng, 2017). The results demonstrate that the prediction errors are acceptable and it can provide a reference for capturing abnormal trend of the axle's temperature. Fault detection in bogies via implementing LSTM network is given by (Yang, Qin, Huang, & Fu, 2018). Bogie vibration signal is considered as input of LSTM and the accuracy of 94% is achieved for multi fault classification.

Deep Belief Network (DBN)

DBN is an unsupervised probabilistic deep learning algorithm which contains multi layers of stochastic feature detectors. In Figure 13 a sample of DBN architecture is shown. As it can be observed, there are connections between hidden layers but no connection between neurons inside a layer which leads to a fast, layer-by-layer unsupervised training (S. Zhang et al., 2019). In (Shao, Jiang, Zhang, & Liang, 2018), a DBN has been developed for electric locomotive bearing fault diagnostics. Reference (J. Yin & Zhao, 2016) developed a DBN for vehicle on-board equipment of high speed railway and showed that the obtained results outperforms the artificial neural network with back propagations (ANN-BP) approach.

Figure 13. Architecture of DBN (S. Zhang et al., 2019)



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Maintenance Decision-Making

The last step of a CBM program is maintenance decision-making which is important to maintenance crew's decision on taking proper maintenance actions. Approaches for maintenance decision–making in a CBM context can be divided into two main categories, namely, diagnostics and prognostics. As mentioned earlier, diagnostics focuses on detection of the fault when it occurs, however, prognostics focuses on prediction of faults or failures before their occurrence which makes better planning for maintenance decision makers which result in huge cost saving and minimum down time of an asset. A CBM program can be applied for diagnostics, prognostics or both. Regardless of the objective of a CBM program, the above-mentioned CBM steps are needed to follow. The main focus of the maintenance decision making is to determine the optimal/near-optimal maintenance policy that minimizes/maximizes a predefined objective function over an infinite time horizon. To name a few, the most objective functions used in the CBM literature are average cost, average availability of system and average downtime of system. In general, CBM decision strategies in both diagnostics and prognostics mainly fall into two groups: (i) Statistical approaches, and; (i) Data-driven approaches.

Most common statistical approaches applied in fault diagnostics and prognostics for maintenance decision-makings are based on statistical process control (SPC) and hidden Markov models.

SPC tools were originally developed in quality control context. By considering the similarity between on-line quality control and CM for maintenance purposes, incorporations of the multivariate SPC tools and concepts into CBM is very attractive. In this setting, a control chart is designed and optimal maintenance policy is achieved which is characterized by different thresholds. More references in this line of the research can be found in (Farnoosh Naderkhani & Makis, 2015) and (Kim & Makis, 2013). In prognostics context, the most common life characteristics of systems such as reliability and remaining useful life (RUL) of the system are estimated. Different statistical method such as HMM, SPC, proportional hazards model (PHM) are applied in order to estimate the life characteristics. More references can be found in (F. Naderkhani, Jafari, & Makis, 2017)[83], (S. Zhao, Makis, Chen, & Li, 2018) and (Khaleghei & Makis, 2016).

In ML based solution and in diagnostics context, there are great literature which the detailed discussion is made in previous section. However, the literature of prognostics via advanced ML techniques is limited. An online SVR technique is applied by (Fumeo et al., 2015) to predict the RUL of train axel bearing. Conventional ML prediction techniques like SVR, RF (Random Forest), and PCR (Principle component regression) are used by (Z. Li & He, 2015) to predict the RUL of train wheels and bogies in a U.S. Class I railway network. Logistic Regression as another conventional ML prediction technique has been applied by (W. Wang et al., 2018) for estimating the RUL of train wheels.

A recent publication in this context is given by (X. Li, Zhang, & Ding, 2019) where deep learning based solution is applied for RUL estimation of bearings. The result shows high accuracy of the proposed model which is promising for industrial application. Similarly, deep CNN is applied by (Xiang Li, Ding, & Sun, 2018) for RUL estimation in prognostic context for aero engine unit.. A multilayer feedforward neural networks based on multi-valued neurons (MLMVN) was proposed by (Fink, Zio, & Weidmann, 2014) to predict the level of degradation of railway track turnouts, where this long-term level of degradation can be used for RUL prediction. It is observed that nowadays there is an increasing surge of interest for applying deep learning-based solution for diagnostics/prognostics purpose in complex system subject to CM.

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This completes our discussion on maintenance decision making.

FUTURE RESEARCH DIRECTIONS

By considering exponential growth of HDMS CM data via advanced monitoring and inspection technologies deployed in RWNs and the fact that nowadays railway is a popular transportation system in world, the combination of these factors has put considerable pressure on the existing infrastructure and calls for an urgent quest to further improve existing automated inspection systems for maintenance purposes. Due to great performance of ML technique in fault diagnostic/prognostic, we believe proposed advanced ML solutions reported in CBM literature will help railroad industry to better maintain and manage rail transport asset. Considering the components of RWN subjected to degradation, the majority of researches have been devoted to track and vehicle monitoring and few studies have considered CBM contexts in signaling sub-systems. Moreover, since CM data in RWN are mainly waveform or image type, the application of deep learning techniques particularly LSTMs and CNNs are still under-examined.

CONCLUSION

In this book chapter, we have tried to review and investigate most recent and novel promising research ideas in the application of state-of-the-art CBM program in context of advanced machine learning techniques that contribute to the energy efficient and smart transportation system via fault diagnostics/prognostics of railway infrastructures and trains. Different techniques, approaches, models and algorithms from conventional maintenance strategies to the advance CBM and newly developed ML algorithms in context of fault diagnostic/prognostic have been reviewed following three main steps of a CBM program, namely data acquisition, data processing and maintenance decision-making. Although recently advanced ML techniques are applied in CBM context, utilization of HDMS CM data in context of CBM for RWNs is still in its infancy.

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Section 3
Information Management

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Chapter 21
A Survey of Ontology-Based Frameworks for Sustainable Supply Chain Interoperability and Collaboration

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ABSTRACT

Accurate and meaningful sharing of knowledge across the supply chain enables effective and timely decision making, a key requirement for ensuring cost-effectiveness, availability, and quality of products and services. Effective elicitation, analysis, classification, and representation of domain knowledge are all essential activities for effective sharing of information. Ontology-based frameworks create a common formal representation of a particular domain that can be communicated, and understood by people and machine agents in addition to integrating different knowledge bases to connect heterogeneous engineering applications. Such frameworks have been exploited in the manufacturing domain as buyer-supplier discovery systems that can be used for quick matchmaking, intelligent connectivity, knowledge-driven collaboration, and possible establishment of stronger, sustainable, long-term, and strategic supply chains. A literature review has identified many frameworks with varying knowledge sharing capabilities that are highly determined by the underlying ontological formalism.

LITERATURE REVIEW

A Survey of Different Approaches in Ontological Frameworks

The main purpose of this survey is cover the topic from different angles and to create a cohesive unit of knowledge based on the large number of references that have been reviewed by the author. The information presented has been collected and referenced from many different sources in an effort to bring valid, pertinent and complementary knowledge that can connect the different areas covered by this research.

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Table 1. Outline of Existing Works

Principles-Guidelines	Toward Principles for the Design of Ontologies Used for Knowledge Sharing, Thomas R. Gruber, 1993
	Knowledge Engineering: Principles and methods, Rudi Studer, V. Richard Benjamins, Dieter Fensel, 1997
Defining and Measuring Supply Chain Interoperability	Using Supply Chain Interoperability as a Measure of Supply Chain Performance. Chalyvidis C, Ogden J, Johnson A., 2013
A Coordination Framework for Manufacturing	Ontology- Driven Coordination for Supply Chain System, Xin J, 2005
A Modular General-Purpose Framework Supply Chain Management	Ontology-based semantic models for supply chain management. Ye Y, Yang D, Jiang Z, Tong L. 2007
	Research on ontology-based integration of product knowledge for collaborative manufacturing, Yang, J; Gaoliang, P; Wenjian, L., 2010
Agile SC Deployment for buyer-Supplier Discovery – A short term solution	Digital manufacturing market: a semantic web-based framework for agile supply chain deployment, Ameri F, Patil L., 2012
	Semantic rule modelling for intelligent supplier discovery, Ameri F, McArthur C., 2014
A long-term extendible, interoperable solution using object-oriented technologies, UML based tools, and creating reference ontology.	Reference ontologies to support the development of global production network systems. Palmer C, Urwin E, Young R, et al., 2016
	Interoperable manufacturing knowledge systems. Palmer C, Young R, Usman Z, Canciglieri Junior O, Malucelli A., 2017
	Exploiting unified modelling language (UML) as a preliminary design tool for Common Logic-based ontologies in manufacturing. Palmer C, Chungoora N, Harding J, et al., 2013
	An Ontology for global production network design and reconfiguration. Palmer, C, Cuel, R. and Young, R. 2015
Exploring Model-Driven Engineering Design Technologies as a basis for Ontological framework development.	Reference ontologies for interoperability across multiple assembly systems. Imran M, Young R., 2016;
	An ontology framework for developing platform-independent knowledge-based engineering systems in the aerospace industry. Sanya I, Shehab E., 2014

Knowledge Representation is an evolving task that needs to be continually adapted and extended in order to be able to address the new challenges and requirements in information management.

Outline of Existing Works

It has also been observed that the knowledge sharing capabilities achieved by an ontology-based approach (framework) is highly determined by the choice of the underlying logic base or ontological formalism. An Ontological Formalism is a formal language that supports the construction of an ontology-based model of the subject matter (Chungoora 2010). To date, several such formalisms have been exploited to develop ontological frameworks that have been successfully implemented to represent the design and manufacturing domains. However, no clear consensus has been reached on a preferred approach.

This survey takes a Software Engineering approach for an overview of several Ontology-based frameworks. Gruber 1993 and Studer et al. 1997 are both highly-cited early works in ontology. Both works have

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been thoroughly reviewed for a discovery of some ontology development guidelines and design criteria. These well-defined guidelines are in clear consistency with the modern day advances in the domains of Systems Engineering and Software Engineering. Moreover, these established guidelines cover a lot of aspects; from software/model development to model-driven architecture and model verification & validation. The survey will identify the requirements for some of the existent frameworks to determine the motivation behind each chosen approach. Each of the solutions will be evaluated for the possibility of reusability and extensibility which are important aspects for building a long-term sustainable solution.

INTRODUCTION

A high-level of semantic interoperability is key requirement for creating sustainable supply chain systems. The ability to represent and share information seamlessly among communicating systems reduces data errors, enables concurrent activities and improves the ability of an organization to deal with change in a timely manner (Das et al. 2007). Effective elicitation, analysis, classification, and representation of domain knowledge are all essential activities for effective sharing of information. One of the earliest and most widely used definitions describes ontology as a shared conceptualization of a domain (Studer et al. 1997). An explicit and formal shared conceptualization of a particular domain creates a common meaning (semantics) that can be formally represented, communicated, and understood by people, applications and machine agents.

As the field of knowledge Engineering (KE) has reached a higher level of maturity, it has initiated a paradigm shift to a modeling view supported by modeling frameworks (Studer et al.1997). The complexity of meaningful knowledge integration and communication has been supported by the development of ontological frameworks (Sanya and Shehab 2014). Such frameworks serve as reference models to describe the organization of the various components used to build the system, and how these components communicate. The diligent choice of a suitable framework to build/develop a specific ontology is the key contributor to successful development and effective utilization of the ontology (Sanya and Shehab 2014).

A very important aspect of an ontology framework is the choice of the formalism representation. An Ontological Formalism is a formal language that supports the construction of an ontology-based model of the subject matter (Chungoora 2010). This formal model enables logic-based reasoning and inference, in addition to automated support for achieving complex data management tasks such as data query and validation. The requirements of a communication language that would enable process interoperation in a cross-disciplinary supply chain (SC) system need to be thoroughly explored (Das et al. 2007). Several families of ontological representation (formalisms) are currently used. Different representations provide different levels of expressivity, formalism (machine understanding) and system interaction capabilities. They also differ in the level of granularity by which they represent the knowledge. Some of the examples of such formalism representations are: Common Logic (CL) which is an ISO standard language based on first order logic (ISO/IEC 24707 2007). Description Logics (DLs) are a family of structured and formal knowledge representation languages that have been used to represent many application domains (Baader,Horrocks, and Sattler 2007). DLs provide logical formalism for Ontologies and the Semantic Web. The Web Ontology Language (OWL) and its profile are based on DLs. One other type of formalism is Frame-based languages (F-Logic) which can be combined with first order constraint language logic.

This survey will identify the requirements for some of the existent Ontology-based frameworks. The main objective is to determine the motivation behind the chosen formalism approach (solution) in each of

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the surveyed frameworks. Each of these solutions will be evaluated for effectivity and for the possibility of reusability and extensibility which are important aspects for building a long-term sustainable solution.

OVERVIEW

This literature review will initially present several introductory sections describing each of the components of the survey title. These components will be the focus of the survey. A brief section presenting each of the ontological frameworks being reviewed will follow. This survey will cover a review of 6 ontological frameworks that were developed (presented) between the years 2005 to 2017. One aspect of the comparison will be to look at the progress in the architecture and design of such frameworks as it relates to the purpose of their development.

Ontologies are well-suited for addressing the modeling requirements of a dynamic environment. By definition, ontologies are extensible and flexible to evolve over time as the domain knowledge increases or as more of the already existent knowledge needs to be formally represented. As the level of formalism or machine understandability of the ontology increases, a higher automation can be achieved. Machine agents; both software and hardware will have a higher level of active contribution while human agents (i.e. system experts) will have a reduced intervention level. A higher automation increases system interoperability and reduces errors.

The careful selection of semantically-rich formalism enables the development of a complete conceptual view of the system that supports effective systems' interaction at the conceptual level and provides ontological support through the entire system's life cycle (design, implementation, run-time, querying & interaction and maintenance).

INTEROPERABILITY

One of the earlier definitions of interoperability is the ability of two or more systems or components to exchange information and to meaningfully use the information that has been exchanged (Geraci et al. 1991). An IEEE standard describes interoperability as the ability of two or more systems or their components to seamlessly exchange knowledge (IEEE Std 1999; ISO/IEC-TR-10000-1 1998). A similar definition describes interoperability as the ability of two or more systems or components to exchange and use shared information (Chen & Vernadat 2004). Yet another definition is the ability to share technical & business data, information and knowledge seamlessly across two or more software tools or application systems in an error-free manner with minimum manual interventions (Ray and Jones 2003). The progression and level of detail of these definitions reveals the ever increasing need to achieve fully automated, accurate and meaningful semantic interoperability across all collaborating heterogeneous applications and for all types of shared knowledge.

Supply Chain Interoperability

Normally, there is a consistent internal terminology within an organization nurtured by similar business backgrounds and business culture. However, Interoperability is not a natural or standard feature among heterogeneous disperse IT systems. This lack of interoperability is caused by syntactic and semantic

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incompatibilities of the information to be shared (Das et al. 2007). Syntactic incompatibilities are caused by the incompatible data structures used to represent knowledge by different participating software systems (Chen 2006). Semantic incompatibilities are related to the meaning associated with the shared information and knowledge (Daclin et al. 2014). Semantic inconsistencies can be observed when the same term is used to denote different concepts and different terms are employed to represent the same entity. Semantic inconsistencies normally occur among different organizations that have different business contexts and cultures. However, they may occur within the same organization due the existence of legacy systems. To achieve semantic interoperability, shared information must have explicitly defined meanings (definitions) and the same terms must have the same meaning (Daclin et al. 2014).

Supply Chain Performance

Supply chain measurements are essential to improving the overall performance of a SC. Organizations that participate in performance measurement activities at the level of the supply chain network and where all individual supply chain partners are well-informed about the results of such measurements have reported improved performance (Laihonen & Pekkila 2016). In a supply chain network, different partners may have conflicting views about how to measure the SC performance. SC partners may also have contradictory objectives. SC management practices of performing systematic measurements and sharing the information from knowledge and learning perspectives with its partners will ensure more collaboration and acceptance among SC participants.

Establishing an adequate supply chain measurement system is a major requirement for evaluating the affectivity of supply chain collaboration. In order to accurately evaluate the level of supply chain interoperability, the measurement focus has to be shifted from individual supply chain partners to the higher level of the supply chain system (SCS).

Supply Chain Interoperability and Performance

A supply chain system (SCS) is considered as a system of systems (SoS). System of systems refers to an interconnection of 2 or more systems that are free to leave or stay in the SoS. Whenever staying, these systems will collaborate, operate in harmony, "put the goals of the SCS before their own" and offer their designated services to the SoS (Broadman & Sauser 2006). In SoS, the individual participating systems are designated as components. In a SCS, the individual systems are often designated as partners. In order to draw the many parallels (characteristics or similarities) that exist between a SoS component and a SCS partner, both entities (SoS component & SC partner) are designated with the neutral term member. Both groups of members (SCS & SoS) are designated with the neutral term system. Such parallels include equivalent member characteristics such as autonomy, belonging (must collaborate), connectivity, diversity, emergence, seeking the good of the entire system before that of a member, a member may have to sacrifice individual performance to improve overall system performance (optimality). Another similarity between a SCS and SoS can be seen in the way the members communicate and exchange information.

This paper offers a technique to evaluate the overall performance of a system based on the performance of the individual members.

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System Sustainability

The global goal of SUSTAINABLE DEVELOPMENT requires the implementation of an integrated approach to sustainability that aims to "develop quality, reliable, sustainable and resilient infrastructure" (United Nations Goal 9). System Sustainability is achieved by managing the complete system life-cycle. At each stage, Provision is defined to allow the system to evolve in response to changes in its environment, usage profile, and business demands. System sustainability is an important system requirement and not an ad-hoc attribute; it has to follow the same rigorous analysis and design process similar to the entire system. Moreover, System sustainability has to be integrated into the software system in addition to the underlying business processes. Planning, provision and the adequate infrastructure for system sustainability form an important project on its own and have to be integrated at every stage of the software development lifecycle. Ensuring software quality attributes such as modularity, flexibility and maintainability is essential.

Modularity and Reuse

Effective integration of complex knowledge is an essential factor in the support of decision-making during the product design process. Ensuring modularity in ontology design supports a long-term engineering design. The creation of small, modular and self-contained ontologies enables effective validation, verification, integration, testing and reuse. As a matter of fact, modularity is the main contributor that leads to flexibility and maintainability. The literature demonstrates that lack of modularity in ontology design has significantly reduced system maintainability and greatly complicated future reuse or upgrade (Fowler, Reul and Sleeman, 2008).

System Development

An ontology-based framework is a software-intensive system. The development of such a system needs to follow the rigorous, structured and systematic approach that has been developed in Software Engineering for software system development. As a matter of fact, literature shows that ontology development methodologies are not matured when compared with Software Engineering methodologies (Sanya and Shehab 2014). Software Engineering methodologies put a large emphasis on the process of requirements engineering as a key stage that determines the outcome of any software project. The rigor and the quality of the activities carried out during the requirements engineering stage of any system development establish the foundation for the subsequent phases of the system development.

From the early times of ontology development in the late 1990s, many researchers have taken on the issue of effective **problem-solving** analysis as a key pre-requisite to developing ontology-based systems. Knowledge Engineering: Principles and methods (Studer et al. 1997) is one of the earliest, and most widely cited references has put a lot of emphasis on the area of problem solving techniques and the applicability to the ontology framework development. At that time, many of the software engineering methodologies and techniques as we know them today were being developed and had yet not taken the shape or maturity level that we have now. These researchers and many other early researchers in the ontology domain have been involved in software engineering research as well. These researchers have supported the modeling paradigm shift.

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System Modeling

"Modeling is the process of organizing knowledge about a given system" (Bernard Zeigler). Knowledge from facts backed-up by research, measurements and any defined assumptions are modeled into an experiment that is applied to the model. The obtained results can be applied to a particular project in order to describe specifications, carry-out system verification and effective decision making. Essentially, modeling is a problem-solving tool (cellier 2013). The Paradigm shift to modeling (Studer et al.1997) has changed the traditional process of knowledge acquisition. Knowledge used to be considered as a collection of already existing information that can be composed or possibly divided into other knowledge artefacts. To acquire this knowledge, a transfer process would take place from the system expert to a pre-defined computer representation based on the type and format of the knowledge. This approach fails to take into account the tacit knowledge and other experience-based skills of the system's expert. Tacit knowledge is defined as knowledge that cannot be explicitly transferred (in a contextual form) but that is applied during problem solving or knowledge representation. Modeling resolves this problem and enables the integration of the tacit knowledge of the domain expert in the model. It has been established that an expert may not be aware of a significant part of this knowledge that is often hidden in the expert's skills and cannot be articulated or transferred in the traditional ways (Studer et al. 1997), this knowledge acquisition process can be well-satisfied during the model construction process.

A Knowledge-Based System (KBS) (i.e. ontological framework) is a computer model which aims to achieve and automate problem-solving, reasoning and inferring capabilities comparable to a domain expert. The modeling process in cyclic and incremental; new observations may lead to the refinement of the model and the model may lead to the requirements to further acquire (elicit) knowledge. This iterative process is very much in harmony with the software engineering rational unified process, an iterative process that is applied at every stage of software development.

The software crisis in the late 1960s, happened primarily because of inadequate software development methodology. The methods used in the development of small academic prototypes did not satisfy the design and maintenance requirements of large sustainable industrial systems. This crisis situation has led to the establishment of the discipline of software engineering. The same situation is currently present with all the prototypes of ontological frameworks and which make it clear that there is a need for a methodological approach to ontology development (Studer et al. 1997). The frameworks under-review are examples of such prototypes created based on a chosen formalism. The next section presents an overview of some of the common ontology formalisms.

Some Common Ontology Formalisms

The following section provides a brief description of some of the ontology formalisms that have been used in the reviewed frameworks. The literature has shown 2 main formalisms to represent Ontologies: Description Logics (DL) or Common Logic (CL). It is important to take note of two basic definitions associated with any formal logic. Formal syntax is the description (definition) of how to write statements in the logic while Formal semantics gives the meaning of logic statements.

Description Logic (DL) is the knowledge representation formalism of Manufacturing Service Description Language (MSDL) ontology. DL provides concepts, relationships and logical constraints and has been DL has been analyzed by NIST based on the provided levels of logical formalism and expressivity as a possible match for the development of manufacturing ontologies. DL provides sufficient expres-

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Common Logic (CL) ISO standard language (ISO/IEC 24702 2007)	
A framework for a family of logic languages used to exchange and transmit information among software systems. These languages (dialects) can have any desired syntax. The concrete syntax of a dialect must conform to the abstract CL semantics. [Wikipedia]. CL provides a rich structural ontology representation, suitable to model complex domains.	
Representation	Enables the utilization of predefined formal process semantics from PSL, which can be used as a base set of concepts for manufacturing lifecycle Ontology. The CL standard includes specifications for 3 dialects that can be translated to the abstract syntax: **CLIF** - Common Logic Interchange Format provides the syntax for CL **ECLIF –** Extended CLIF, heavyweight approach able to capture integrity constraints, ensuring that the real meaning behind terms coming from different systems is the same (Das et al. 2007). Operates using the closed world assumption (what is currently not known to be true, is presumed to be false) and different names represent different concepts). More efficient execution than the alternative rule languages Intuitive approach for IT professionals (software engineers or database specialists) Enables computational comparisons of the meaning of terms and facilitates process interoperability. **CGIF** - Conceptual Graph Interchange Format **XCL** XML Based notation for CL
Concepts	Based on first order logic and uses predicate logic-quantifiers and relations.
Functions	Ontological functions, disjunction and negation.
Relations	Can capture ternary (3-way) relations to represent manufacturing processes
Advantages over Other Languages	CL is more expressive than OWL and RDF and has more powerful deductive reasoning. Suitable for manufacturing design since it is facts-driven and requires the closed world assumption
Challenges	Does not describe manufacturing capabilities or components. Limited extensions for particular types or processes were proposed.

PSL-Process Specification Language (NIST) (ISO 18629 (2004))	
Describes process Flow, communicate between machine control s/w & process planning s/w	
Representation	written in CLIF Represent process-related knowledge. A neutral representation for integrating process data throughout the manufacturing process life cycle. Support application integration Description of basic manufacturing, engineering and business processes Integrating process-related applications: production planning, process planning, workflow management & project management
Concepts	activity, object, time-point, relationship
Functions	Functions in ontological terms are expressions that enable individuals of classes to be denoted in terms of individuals from other classes. Ontological functions are needed to represent the manufacturing concepts 'beginof' and 'endof' which are defined in PSL. Unary functions: datatype properties, attributes: int, float, string, etc.
Relations	participates-in, between, before, occurring-at
Challenges	Does not describe manufacturing capabilities or components. Limited extensions for particular types or processes were proposed.
ISO committee: TC184/SC5/WG1: A standard for process interoperability in Virtual Enterprise	
Representation	Less manufacturing processes description. Improve process interoperability Defines the Components & attributes of an enterprise process model
OWL-S Semantic Representation of Web services	
Enable automatic service discovery, invocation, composition and interoperation. A comprehensive picture of a service: A profile: what it does, A model: how it works, Grounding: how to use it	
Challenges	Web Services are software components and do not have the necessary building blocks to describe manufacturing services.

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sivity for application. There are many advantages for using DL as a mathematically rigorous formalism. DL supports automated reasoning, concept subsumption (a concept is absorbed within another or sub-concept relationships), equivalence and consistency. DL is supported by the semantic web; DL-based ontologies can be shared, parsed and manipulated through web-based tools and technologies OWL-DL is the ontology modeling language of MSDL, OWL-DL is recommended by W3C as the ontology language of the semantic web. OWL uses XML as the syntax language. XML is portable, flexible and extendible. The Semantic Web Rule Language (SWRL) can be used to write rules (constraints) in order to associate instances to classes and to create associations between instances. The rules supported by SWRL can be used to represent rules such as property, association and partOfrules. However, SWRL does not support disjunction (logical statements using or), negation (using not) or integrity constraints which are restrictions on the constructs present in an ontology that can prevent modeling mistakes. SWRL supports binary relations only and uses approximations to estimates ternary relations by adding arguments or break a ternary to form 2 binary relations (Chungoora 2010). Such approximation leads to a loss of original semantics and could lead to ambiguities.

Knowledge Interchange Format (KIF): A formal, propositional and descriptive language with declarative semantics. KIF can express arbitrary statements in first-order logic and describe general facts about the world rather than processes or procedures. Primitive concepts to describe knowledge: objects, functions, relations, and rules.

Knowledge Frame Language (KFL): Based on ECLIF, a dialect of CL and provides constructs to facilitate ontology building based of frame-based primitives. KFL constructs are more readable than ECLIF and facilitate code reuse, thus enabling more efficient development and allowing smaller, consistent and more manageable ontologies to be built (Palmer et al. 2013). KFL facilitates an explicit and intuitive representation of knowledge.

Ontolingua: Developed at Stanford University Knowledge Systems Laboratory (KSL). Based on KIF, same logic formalism as IDEF5 elaboration High level of expressivity, allows representation of concepts, taxonomies, n-ary relations, functions, axioms, instances and procedures (Gruber, 1993)

Context of Use Model

Problem-solving methods have been a major research topic in Knowledge Engineering and many of these methods have guided the development of ontologies. Based on the interaction problem theory, investigated is early ontology research, it can be seen that knowledge representation has a strong relationship to its use and that knowledge cannot be represented independently from its use (Tom Bylander & B. Chandrasekaran 1987). Thomas Gruper, 1997 presents the interaction and design requirements for ontologies in knowledge sharing applications. Alongside a set of ontology design criteria, the requirements describe a "**usage model"** for knowledge sharing ontologies. A usage model is similar to a use case model in software requirements specifications. A usage model is defined for a set of software agents and a set of clients. A usage model is composed of several scenarios where each scenario describes a set of interactions between a client and an agent to achieve a prescribed goal. Based on the usage model requirements, a set of design criteria (similar to non-functional requirements or quality attributes) along with the "How To" apply and measure are proposed.

It is important to carry out a thorough and effective evaluation of the context of use of the system, users and their environment, stakeholders and their concerns, before any further decisions are taken about

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the actual development of the framework. The literature review that was carried-out did not show such analysis. Many widely-used software engineering methodologies supports the accomplishment of this task.

New Methodologies: There is a recent methodology trend shift that primarily aims to evaluate the available methodologies from other disciplines (e.g. MDA) and the tools used in other software development areas (e.g. UML) for their feasibility for ontological framework development. Two main interoperability initiatives were developed and documented with similar results that support the above mentioned methodology initiatives (Chen, Doumeingts, and Vernadat 2008). The first initiative is ATHENA (Advanced Technologies for Interoperability of Heterogeneous Enterprise Networks and their Applications). The second initiative is INTEROP (Interoperability Research for Networked Enterprises Applications and Software). Both ATHENA and INTEROP frameworks emphasize the need to integrate/merge three research themes/domains for effective development of enterprise applications interoperability. The 3 research areas are enterprise modeling, architecture and platforms, and ontologies (Panetto, Scannapieco, and Zelm 2004; The-ATHENA-Consortium 2004–2006; Kosanke and Zelm 2005).

Research is being currently developed on Model-Driven Interoperability (MDI) architectures, based on the model-driven architecture (MDA) concepts. MDA is a framework introduced by the object management group (OMG) (http://www.omg.org/mda/). This is the same group that developed and supports UML and associated tools. MDA supports the creation of highly abstract, generic, machine readable models that can be specialized and transformed into domain-specific models to support interoperability (Sanya and Shehab 2015). MDA, has 3 main components or models. The Computation Independent Model (CIM) to define system requirements. The Platform Independent Model (PIM) to describe a software solution at a high level of abstraction and that is technology and platform independent. And Platform Specific Model (PSM) which describes the deployment of a model based on the chosen PIM for a particular platform (Chungoora et al. 2013).

Comparative Review

The following enumerated sections will provide an overview of some of the frameworks reviewed; they will demonstrate the progression over time from a simple coordination system that requires the manual execution of steps and model communication to more automated highly intelligent systems. The review will also rationalize on the process followed in order to achieve system interoperability and sustainability.

The following sections will present the comparative value of the different ontological frameworks under review from different aspects as they relate to the title of this paper. These aspects include ontological formalism, development methodology, the achieved level of automation, in addition aspects of modularity, extensibility and sustainability.

1- Ontology-Driven Coordination for Supply Chain System

This framework addresses the semantic interoperability needs of SCS that integrate multiple manufacturing distributed processes such as supply, manufacturing and sales. Semantic interoperability enables heterogeneous information systems to exchange queries and transactions. Each application may have different application ontology (AO) to support its specific purposes. One of the main concerns for this approach is that descriptions based on the same object and expressed in different ontologies may lose some natural relationships. Mapping between different ontologies is required for different SCS members to interoperate and achieve knowledge-driven collaboration in areas such as service discovery (e.g. sup-

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plier), command translation, task identification, information queries, etc. This framework uses lightweight UML-based approach to represent primitive Ontology (class diagrams) and uses RDF constructs such as subClassOf, subPropertyOf, equivalentTo, etc. for readability. Each AO includes the concepts subject, task, process and method as specific to the domain. Using UML, ontologies can be created similar to domain models in software development: Entities with domain specific attributes and relationships with the domain and with other entities. Levels of constraints can also be associated with attributes both in the class diagram and using object constraint Language (OCL)

A semantic mediator (SM) equipped with semantic preserving mapping and interoperation logic among the terminology of the different applications will enable semantic interoperability. Different applications can have different types of ontologies for different purposes and be able interoperate by means of mapping one ontology to another and allowing accurate translation and execution of queries. The mapping process requires 2 basic functions association and identification: "Associate between different ontologies and choose the right methods to perform the identification" This is very similar to strategy design pattern in OO methods. The SM used information processing and pattern recognition algorithms to extract the needed information from the ontology definitions. Identification makes provision for ontology extension and reusability. When new collaboration is established, it identifies the appropriate entity(s) in the current ontology that can be used to represent new information. This is an important requirement for achieving system sustainability.

Mapping Mechanism: Different AOs can be defined as independent UML class diagrams. Knowledge about the associated domains is expressed in a UML object diagram as instances of the ontology classes. A series of manual transformations is performed to enable model exchange and encoding. However, there was no simple way to encode object diagrams.

Contributions: This research provides a basic high level approach to represent and map ontologies that has been exploited in future research is good. It also provides an extensive analysis to justify the use of UML class diagrams for knowledge representation, one of the earliest initiatives in the field of ontologies.

Disadvantages: This framework uses model transformation tools. This involves many manually executed steps with the possible side effect of loss of information or details. Implementation is not efficient. More advanced object technologies exist now to be investigated and can be used to refine the framework.

2- Ontology-Based Semantic Models for Supply Chain Management (Onto-SCM)

Onto-SCM is a general and modular approach to Supply Chain management (SCM) that provides general concepts and relations that are shared in SCM as a domain. The main purpose is effective SC integration by addressing the semantic incompatibilities that exist among SC partners and creating a SCS with high flexibility and agility. The semantic model of the ontology is constructed in a modular way. Such a methodology aims to create a sustainable software solution that can be reused and maintained. Similar to the initial step of a software project, where domain modeling is used to create a shared understanding of the key domain concepts, this solution uses the IDEF5 schematic language to create an initial visual representation of the ontology. Such a representation creates a common visual understanding of the domain among different stakeholders (i.e. knowledge engineers and domain experts) before the actual ontology capture process. IDEF5 defines an elaboration language as well but was not used due to complexity, lack of modularity and limited language features [citation?]. Ontolingua is used as the ontol-

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ogy representation language and it supports the translation between multiple representation languages. Ontolingua extends KIF with frame ontology so it can define both object-oriented and frame-language constructs for an expressive ontology construction. Such constructs include class, instance, relation, function. A class definition has a name with an argument list (attributes), an informal textual description and a formal axioms part using KIF and frames constructs.

Onto-SCM presents SC-Management as a main modular theory (similar to package in object-oriented terminology), SC-Management depends on 4 other modular theories: SC-Structure, SC-Activity, SC-Resource, and SC-Item. Each theory defines a set of related terms. The terms can be used (class definition), instantiated (to create objects), or specialized (parent-child inheritance) to describe a specific SCM application.

Semantic Mapping: Different partners in the SC use different applications and each application is represented by a different ontology. To achieve semantic mapping, Onto-SCM identifies the general terms and relationships common to all the applications and constructs a neutral interchange language. Now, semantic mapping can be implemented between different AOs and Onto-SCM by describing instances of translations (equivalences of terminology) between concepts/relations in AO and Onto-SCM. A mapping rule is expressed as an inference of the form: premise→consequence, where a premise is (knowledge known in one ontology), and the consequent is (semantically equivalent knowledge in the other ontology). Both premise and consequent are expressed in KIF, mapping rules are expressed in KIF as well. Another feature of this framework is IDEFOnto which gave a convenient way to graphically model, visualize, and navigate through the represented knowledge. IDEFOnto is based on the IDEF5 schematic language that has been used for initial domain mapping. This tool is used by both knowledge engineers and system experts with a high level of usability and flexibility. It can be used to express, display, add, modify, and delete entities. Knowledge and ontologies can be viewed/stored in visual diagrams and can also be transformed into Ontilingua ontology files. This is a highly extendible solution, as knowledge changes due new models or structures, new semantic rules can be added.

Disadvantages: Creating mapping rules between instances of classes is very lengthy. Recent object-oriented solutions allow the mapping between the abstract classes and the inference rules will follow to the instances of these classes?

3- Research on Ontology-Based Integration of Product Knowledge for Collaborative Manufacturing (OntoGen)

The optimization of knowledge integration in collaborative manufacturing can be best approached by transforming the knowledge integration into ontology integration. Describe a collaborative business process in order. Integration between local and global ontology based on similarity.

4- Digital Manufacturing Market (DMM)

This framework has specifically been designed for supplier discovery. The main purpose is meeting short-term needs of a global, distributed and agile SC in a timely and accurate manner. Selecting suppliers that can fulfill the requirements for a given work order or a specific part while achieving the business goals of a global and agile SC requires the discovery of many suppliers in various geographic locations; a requirement that cannot be fulfilled through traditional supplier selection methods. A web-based framework facilitates such an interaction. Two major areas of research are addressed: manufacturing ontology

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and matchmaking in agent-based frameworks. Manufacturing services are complex. An adequate representation of a manufacturing service must provide a complete process lifecycle specification as well as a description of the capabilities and components that characterize this service. The existing ontologies did not enable the required level of expressivity or automation. Moreover, available agent-based tools and platforms did not provide the required search capabilities. An agent-based approach is suitable for modular, distributed applications and provides a high level of automation. In this case, the supplier selection is a multi-criteria problem which requires a multi-agent approach that can implement different strategies based on the required criteria. Machine learning logic can be used to enable machine agents to refine their searching and matching algorithms. DMM incorporates 3 types of machine agents: sellers, buyers and middle agents. Middle agents implement different matchmaking methods.

The DMM approach is not fully-automated: Human agents supervise the operation of machine agents by launching the needed agents and loading them with the required domain and reasoning knowledge as required. MSDL is the ontology, the underlying logic is of DMM which describes manufacturing capabilities and needs of sellers and buyers. MSDL is a light-weight ontology that provides basic abstract concepts and is flexible to handle the heterogeneous environment. MSDL is based on DL. Middle Agents have 2 major roles: Maintaining and updating a directory of active seller/buyer agents in the market and processing the queries submitted by the buyer/seller agents (matchmaking). Seller agents subscribe to a yellow pages middle agent while buyer agents submit a request (RFQ) to a blackboard agent. An agent finds appropriate matches based on the desired service, actor (buyer/supplier), and required part. Depending on the search criteria, multiple middle agents may be implemented and work on the matching. The buyer/seller agents may implement some logic as well. Matchmaking can be based on a hierarchy and/or desired features.

UML and Object Oriented Modeling

There is a widely accepted view that object-oriented (OO) modeling is a natural intuition to the way people perceive common natural objects (Booch, Jacobson, and Rumbaugh, 1998). There has also been a growing quest to reduce the gap between concept representation in the real world and the software implementation of these concepts. These reasons and many more have backed up the paradigm shift to object oriented development techniques.

UML is a widely-used Object Oriented design tool that is considered as a standard to represent software designs. UML has become a widely spread technique in the software industry as a main OO modeling, analysis and design graphical tool. UML provides an effective extendible and scalable approach to ontology and conceptual modeling (Cranefield and Purvis, 1999). UML provides a graphical modeling syntax which is different from other logic-based textual formalisms so it is highly usable. Similar to a reference or foundation ontology, UML provides a metamodel that defines the type of concepts and relations that can appear in a user-defined model or application ontology. Knowledge in UML is highly modular and can be easily, changed extended and reused. UML can be used to represent ontologies based on CL. UML tools are intuitive design tools that would facilitate the ontology construction process. UML is supported by numerous open-source tools and on-going research. Some of the most widely used tools are Rational Rose (IBM), Enterprise Architect (Sparks Systems), ArgoUML (Tigris.org), PapyrusUML (An Eclipse UML modeling environment that supports both UML & SysML) and that allows for code generation based on UML models. Using UML for ontological design strengthens the collaboration between knowledge engineers and software engineers and can facilitate the usage of ontology definitions

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for generating working software code. Palmer et al., 2013 demonstrated the applicability of UML as a preliminary design tool for Common Logic based ontologies.

Designing Ontology

Various Ontology-building methodologies have been developed. Ontologies are either built from scratch or by reusing and extending an existing ontology. These methodologies utilize different tools and languages. Not many tools exist with sufficient expressivity to represent the concepts of CL. CL has been recently developed and not many compatible tools exist. Two methodologies have been identified: conceptual graphs and IDEF5 (schematic & elaboration languages) IDEF5 schematic language provides limited graphics visualization tools. There is a need to adopt a tool that is compatible with CL but also provides graphic representation for building ontology. Regardless of the approach taken to represent an ontology (CL or DL), design tools are needed to facilitate ontology development.

Gaps in Available Research

At a technical level, the work and research being done in Ontology framework is very similar to some of the work that has already been done or in the development process in Software Engineering (Studer 1997). At the moment, Ontology research is a smaller area and must be in harmony with the new development trends and approaches in Software Engineering and systems engineering. Some of these main areas include model driven architecture, architectural viewpoints and requirements engineering. The development and effective utilization of successful and sustainable engineering ontological frameworks will be strongly determined by the methodology used to develop them. Ensuring applicability, validity, modularity, and extensibility in ontology design is essential for building a long-term effective engineering solution.

Contrasting Opinions

The main contrasting views that have been found in the reviewed literature were related selecting the most suitable language formalism for representing the ontology. Each research has argued that the chosen approach is the best approach in terms of expressivity, reasoning, inferring capabilities or other capabilities. It would be very useful if a comprehensive review is carried out for all the available formalism such that it can be used as a reference for selecting an appropriate approach for future frameworks.

Another contrasting view was related to the arguments “For” or “against” the use of UML for ontology design. Some of the arguments against using UML for Ontology Design are based on outdated versions of UML and do not take into consideration many of the new features that are available in the latest releases of UML. A comprehensive review of the possibility of exploiting UML as a modeling tool for ontologies was carried-out (Palmer, Chungoora et al. 2013). A review of this document by the author has revealed many important evidence and reasoning for using UML but it was noted that some of the more recent features provided by UML such as the profile facility were not covered in this review. This could be the subject of future research.

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CONCLUSION AND FUTURE WORK

The development of ontological-based frameworks is an iterative process. One main purpose of this paper was to find a sustainable solution. A sustainable solution requires sustainable interoperability. Sustainable interoperability can be achieved by creating a solution that can be reused and extended and also supported by many tools and current research in different engineering areas. Research work in ontological framework design should not be carried-out in isolation from other work in software development and advancements in the disciplines of computer engineering (MDA) software engineering (domain modelling an requirements), systems engineering (modeling and simulation), artificial intelligence and machine learning. Model-driven technology is an enabler for achieving sustainable interoperability.

The author would like to build on some of the current research in the areas of Model Driven Architecture, Object Oriented Technologies and UML profile feature. Namely, explore the use of some of the integrated UML tools such as Papyrus or Rational Rose that support Model Driven Architectures, model validation and transformation and how they can apply to ontology development. Another area would be to explore how some of the Software Engineering methodology can be applied to ontology framework development.

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Chapter 22
Impact of Cloud Computing on Green Supply Chain Management

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ABSTRACT

Almost every market in the world aims to go globally as wide as possible. It is important to understand the need for information and internet merged together in order to achieve such goal. Cloud systems are the new way of delivering and managing information to different parts in the world in a secure manner. However, not many organizations have moved to cloud. The rely of green supply chain management systems on cloud is not as popular as expected and not increasing fast enough. There is a trust issue raised against cloud and the adoption to it. Cloud can bring different benefits to green supply chain management systems such as the low cost of running, speed of dealing with information, and information availability which can have significant impact on energy savings. Organization contribution in the process of moving to cloud is important to attach any knowledge database to take competitive advantage.

INTRODUCTION

Information technology has been changing the way business works interlay through over the past few decades. More information to analyze and more to process. One of those areas is cloud computing. Cloud computing is a new technology that can be defined as a group of distributed computers powers that works together to process different sources of data and deliver solutions through common pool online. Different companies built huge data centers and offered public cloud services to end-users such as Google and Dropbox. Also, companies use such powerful data centers to introduce different solutions to business. Companies can use such cloud computing services to increase the efficiency and speed of works all over the process. The impact of cloud computing thoroughly reformed how industries operate specifically in Green supply chain. Cloud computing introduced some tasks for companies like data storing and accessing of online software with real-time data updating. To go through these developments,

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we did summary surveys that evaluate some research papers that study the impact in the green supply chain in those major aspects: Architecture, Optimization and Information Sharing.

BACKGROUND

Architecture for Green Supply Chain Network Simulation

This part introduces a cloud computing architecture solution (CCAFSCNS) to shorten the time significantly when the simulation is applied to test the performance of a green supply chain. Since the main reasons for companies with large-scale multi-echelon green supply chains and complicated behaviors of different participants is predicted green supply chain performance, track the system performance, achieve what-if analysis and compare alternative system configurations, simulation techniques can take a long time. And companies needed to find a rapid simulator to do so. To test (CCAFSCNS), the res assumed four characteristics described in Rossetti and Chen (2008). After that, a details establishment was introduced for the system architecture which includes the following layers: data layer, data tools layer, cloud computing system layer, web application layer, simulation layer, and prototype layer. To compare the time spent on simulate on the local computer and the time spent on the cloud computing solution, the solution may be classified into four components: (A) startup time of VMs, (B) scheduling time, (C) execution time and (D) file transfer time. Then, the paper compared between Traditional Solution and Cloud Computing Solution. To conclude, from Comparison, the cloud computing architecture solution can significantly shorten the simulation time.

Adoption of Cloud Computing in Manufacturing

The research provided by the author is an effort to fill the knowledge gap of implementation of the Cloud Computing Technology (C.C.T) in the manufacturing technology and improve its green supply chain performance. The manufacturing industry is chosen because the business in this industry is becoming increasingly IT-resilient, globalized, distributed and agile demanding (Ali & Imran,2013).

Theoretical Framework

The maximum capacity of cloud computing? According to a recent Merrill Lynch study, cloud computing is expected to be "$ 160 billion in commercial and productive applications, and $ 95 billion in management opportunities, $ 65 billion in online advertising." (Lindner et al., 2011)

There are three types of cloud deployment models proposed by the author:

- **Public cloud:** The Internet is featured by the presence of an external service provider and is particularly a cost-effective way to implement IT solutions for small and medium-sized enterprises.
- **Private cloud:** Public cloud computing provides many benefits to the environment, but organizations manage FV it. Private clouds provide better control over the cloud infrastructure and are often suitable for larger objects.

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- **Hybrid cloud:** Combination of public and private clouds - In general, non-critical information comes from a public cloud, while commercially critical services and data are kept under the control of an organization (Ali & Imran, 2013).

The important points that appeared of the perspective are summarized in this:

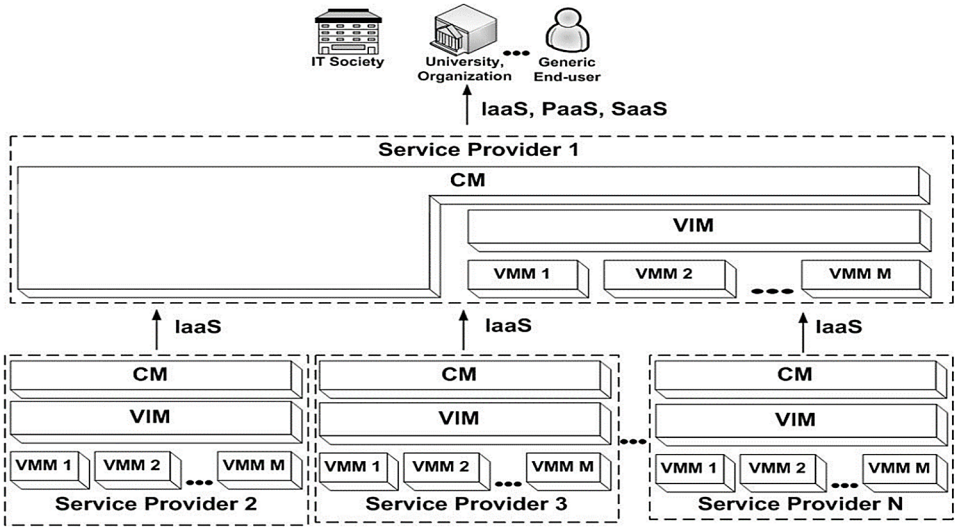
- Considering the above, this study shows that the manufacturing industries should examine the degree of application of cloud computing technology in more detail.
- Investigating the factors that contribute to the acceptance of cloud computing from manufacturing industries and preventive factors.
- Organizational factors affecting the adoption of cloud technologies by organizations/industries need to be considered
- Cloud computing technology promotes innovative products with a commercial strategy but should be analyzed and how it will affect manufacturers in an agile environment.

A possible classification of the cloud architecture can also be included in the three-tier stack (Li et al., 2012): Virtual Machine Manager (VMM), Virtual Infrastructure Manager (VIM) and Cloud Manager.

How to enable a cloud service provider to use external cloud infrastructure providers:

The infrastructure of a computer that moves to a VIM level may belong to a service provider or provide external infrastructure providers (as shown).To create a vertical green supply chain, we created a three-stage stack to meet the demand for a cloud-based enterprise ecosystem where cloud service providers work together based on business agreements. In the scene set in Figure 1, applications for service customization one can be processed and eventually transfer to service provider 2, 3 in the CM layer. (Which acts as an interface between the "world" and the infrastructure)

Figure 1. Applications for service provider (Li et al, 2012)



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- This requires a special procedure to monitor the status of the requested service and to store the information if it is deployed (which is the specific VIM middleware on which a service is deployed);
- It has access to VIM intermediate services via the Common Interface to send frequently used commands to VIM (for example, starting, stopping and destroying).

To obtain information on the resource allocation status of each VIM middleware, you must use a uniform method to identify this information, regardless of the VIM implementation.

THE XRI TECHNOLOGY: The XRI protocol provides a standard syntax for identifying entities, regardless of any particular concrete representation.

XRI enable the organization to organize entities building XRI tree logically

Why Does XRI suit to Cloud Computing? It can be adopted to develop a seamless mechanism to retrieve data regarding composed PaaS (Li et al., 2012).

Linked Data Concepts in Green Supply Chain

Almost every market in the world aims to go global as wide as possible. It is important to understand the need for information and Internet merged in order to achieve such a goal. Cloud systems are the new way of delivering and managing information to different parts of the world in a secure way. However, not many organizations moved to the cloud due to different aspects that will be discussed in the next parts (Yinglei & Lei, 2011).

The relay of green supply chain management systems on the cloud is not as popular as expected and not increasing fast enough. There is a trust issue raised against the cloud and the adoption to it. Cloud can bring different benefits to green supply chains management systems such as the low cost of running, the speed of dealing with information and information availability. Organization contribution in the process of moving to the cloud is important to attach any knowledge database to take competitive advantage. The two issues facing the change to the cloud in SCM systems is the trust concerns and adoptions process. Communication has a positive effect on both issues (Liu et al., 2012). Communication is known as the process of exchanging clear information between different sides with time and date limit. SCM learning process needs a certain information level. In order to achieve such level, different information holders need to maintain mutual trust. They are learning to provide the company with a new base of knowledge to reach targets. As learning increases, the trust and adoption of cloud in SCM systems and have a positive effect on both sides. Participation in relationship skills among different aspect of the company will affect SCM systems. Different partner's contribution and sharing in the goal decision side will increase the performance of SCM systems. Trust will be raised on cloud and adoption will be possible. Usability and reliability are other aspects that affect trust and adoption in SCM systems. Users could be performing better if there were proper presentations and training before asking to trust and change to the cloud. Information needs to be delivered (Yinglei & Lei, 2011) in good service quality as well. Security is the most important side of the cloud. Securing cloud to ensure data secrecy and integrity for the SCM systems is important. Users need to ensure and trust the confidentiality of their data and information before adopting to cloud (Robak et al., 2013).

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Design on Enterprise Knowledge Green Supply Chain

we begin by discussing the small and wide proposed meaning of knowledge green supply chain (KSC) by Chinese scientists, and based on this, puts the definition of Enterprise Knowledge Green supply chain (EKSC). Then the three problems are required to be resolved in constructing the EKSC argued which belong ignorance of the peripheral Branches of the Enterprise Knowledge Green supply chain (PBEKS).

The identification and segmentation of knowledge of users EKSC and the high-level requirements of the timely response of EKSC: In the meantime, the methods and ideas of the Cloud Computing are accepted in order to solve these problems and the impact that brought the EKSC from cloud computing is conveniently proposed. These effects are encouraging companies to attach importance to the PBEKS and provides distributed storage and distributed computing capabilities and essential improvements in communication and teamwork of EKSC By analogy, the principles of design and design thoughts are displayed based on an analysis of the principles and mechanisms of functioning of the branch and converging of the blood circulation of the human body system. According to the principles of design and design thinking, the design of the general structure of EKSC based upon Cloud-computing and the detailed design of the structure of resources of Cloud-computing- based PBEKS are given.

Using Manufacturing Service

Due to fast paced changing market needs and highly demand customizable products, green supply chain involvement is a crucial necessity in the future production manufacturing environments. These trends could be found in many branches of the high-tech industry, such as automotive, photovoltaic, semiconductors, and consumer electronics. In this part, a detailed explanation is presented for the interconnection between the factory-IT systems and the flexible production networks by defining the process of service description which includes all the technical and product-related contents as well as business and logistics information in the cloud manufacturing and Manufacturing-as-a-Service system. The product customization requests force the manufacturers to work closely with their suppliers for more convenient information exchange on product specifications and to align with each other in terms of delivery and other logistics details (Bohlouli et al., 2014)

This part focus on introducing manufacturer as a service, firstly the service provider will register its services using UDDI. Those services are described using WSDL protocol, whenever the consumers want any service or product creation from those manufacturers it will contact the Maas infrastructure to find the suitable service provider and do the binding process between the consumer and the service provider, so the following entities are defined in our MaaS:

- Manufacturing service providers.
- Manufacturing service consumers.
- Manufacturing service integrators.

In the figure above manufacturing service processing is depicted, where the service providers which are the manufacturers in our case take off the services descriptions provided by the manufacturer from their internal IT system like ERP (Enterprise Resource Planning) and MES (Manufacturing Execution System) and publish them to a MaaS infrastructure to enable the customers to access those services and customize their products in any way they want (Tsao et al., 2010).

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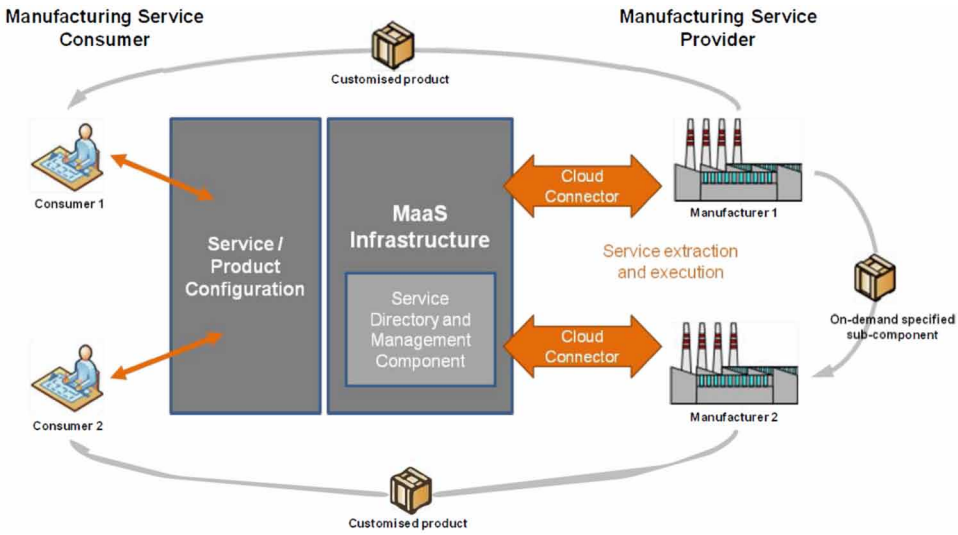
Figure 2. Manufacturing service processing (Rauscheckerl & Stohrl, 2012)



The study aimed to develop a system that only coordinates the manufacture of complex configurable products through various production and places, which does not allow the limitations and capabilities of the production network explicitly available for the process of specifying the specific product. However, work in the field of MaaS is not finalized yet. In addition to managing the challenges described, still has a bit of effort to be put into the alignment of different aspects to be covered by the service descriptions

Enabling Green Supply Chain Collaboration in a Hybrid Cloud

Many companies provide a Rapid Service Infrastructure (IaaS) model for application development and packaging applications by providing them to clients at home or third parties. However, many problems arise when cloud computing, highest security (reliability and integrity of trusted data and transit), performance and availability, while resource and time are the first benefits of cloud computing. (Rossetti & Chen, 2013) Other cloud-related issues include integration issues with in-house IT systems of large enterprises. As more applications and platforms play in the public cloud, there are additional requirements for integrated integration into the enterprise database (Wei & Zhai, 2012).

This section is based on the experience of deploying such a solution to exchange information about the global green supply chain with appropriate data integration with private Cisco cloud that enables the use of a hybrid cloud model (Chebrolu, 2012).

Architecture

In general, the rules for secure cloud architecture are tracked to minimize and mitigate security and privacy risks associated with a general cloud. Each platform interface, including web servers, application servers, middleware components, and database servers, can be deployed in any Virtual Private Data Center (VPDC) in the public cloud Savvis IaaS. Within the VPDC, various components of the Cisco Enterprise support platform include different sets (Web servers, application servers and databases).The

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Apache Web server creates a reverse proxy server, then the application level, data level, and finally the server's level on which firewall and administration functions are handled (Celesti et al., 2011).

Security Controls

Various security models are implemented for control and scrutiny of the system presented in the architecture by the author. Federated Authentication and 'Single Sign-On' techniques are provided for user-level security. Periodic Auditing and Data Level Security, typical for relational databases are provided as scalable fine grain authorization are prioritized. The implementations of Perimeter Firewall, VPN Gateway, Server Tier Level Firewall, Host Level Firewall, Hardening (Closing of unnecessary port and unused applications), Web Application Penetrating Testing, Malware Scanning and Vulnerability Testing are done. Finally, the Transport Level Security including SSL VPN (Browser to VPN Gateway), HTTPS, SSH Pipes (Web Server and App Server) is used.

This document can be used as one of the leading industry architectural, and industry guidelines for individual developers and companies deploying home grew or third party vendor packaged application platforms at IaaS public cloud providers in the marketplace like Savvis, Amazon, Terremark, Rackspace, etc.

An Approach to Enable Cloud Service Providers to Arrange IaaS, PaaS and SaaS Using External Virtualization Infrastructures Cloud computing is represented more than a business opportunity for the operator to increase their revenue. That is because it offers new business for both services' provider and their clients (Chebrolu, 2012).

Customers demand more completed integrated services became higher. In order for companies to follow this kind of adoption agreements between different organizations are needed. Data linked is harder as data capacity is getting way larger than ever. Linking different locations and services requires a lot of IT support and business modeling. New network environment with proper applications implemented is a key point to adapt to a good cloud linked system that can handle large data. Company internal network manages different parts within the system. This handling includes everything from customers to manufacturing. The business process contains different tasks that help in the business decision process and actions. These tasks can vary from small type of data to huge data that cannot be handled easily without proper IT system.

Dealing with Big Data

Big amount of data is considered as a good point because the ability of forecasting and analysis will be higher. Big data means accurate results as there will be more examples and samples to compare and work with. The problem with this is the tools and IT support required to deal with such huge databases. Another problem is the processing time of data. Accurate results for management's decisions need time to prepare and report, as the amount of data is big. Moreover, data is not with the same format type. Different data can be delivered to applications with different formats and origin, and this will make it harder to collect and analyze data in a proper and fast way. Different databases like SQL is not reliable in case of big data handling. Despite the different solutions SQL offers it is still a problem faced. Usage of data is a concerned raised as management discard the result of data gathered from a large amount of data. There are different solutions to continue benefiting from these results; one of them is the delivery

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of these result to different parties or using it in another form. Data pool handles big data streaming in the data collecting process at it is.

Store data in SQL and OLTP is considered as an old method of analyzing. Different ways were implemented in order to enhance the concoction process and get the information promptly with proper reporting and feedback. By using a cloud that is capable of handling bid data performance and deacon, making is way better. Making a common format is a solution for data to help in the process of exchange between different parts and networks. Automated data extraction is possible as data linked openly on the web can be supported and gathered. Social media is a huge popular communication network in the past few years. The collection of such data is a valuable thing;however, it is an expensive process in terms of database and handling. Social media is helpful in terms of organization forecasting.

Lambda architecture that is used to handle big data by merging it with real-time support of creating data reports is a helpful way for decision and logistic teams.

OPTIMIZATION

What are improvements that cloud computing performed for the green supply chain?

We will divide the improvements in the green supply chain into three types:

1. Service green supply chain
2. Manufacturing green supply chain
3. Hybrid green supply chain

Optimizing the IT Business Green Supply Chain Utilizing Cloud Computing Summary

Cloud computing arises as a technology to promote IT costs and maintain flexibility. Enterprises are incrementally moving to cloud computing in an exploratory, ad hoc manner. This document describes the requirements for the architecture and implementation of a set of components to optimize the IT green supply chain with the use of cloud computing.

Almost all IT services and hardware and resource support are “a logical data center” that can be enough data centers and dependencies on managed business and hosting service providers (MSPs), But the conceptual model is a single data center, although it is hybrid. Cloud computing for business applications implements the green supply chain management model in a way that converts the IT services of a vertically integrated green supply chain into a computer (Ferguson & Hadar, 2011). The company reflects the resource requirements of IT services for several cloud service providers, including:

- Software-as-a-Service (SaaS)
- Business-Service-as-a-Service
- Platform-as-a-Service (PaaS)
- Infrastructure-as-a-Service (IaaS)

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They used the IT Cloud Service (ITCS) for IT services following this hybrid, automated, managed development model Figure1. The release of the new model requires new cloud service optimization software (CSO), which resembles ERP (Enterprise Resource Planning). The chapter explains:

- The requirements of CSO software systems.
- The service lifecycle and a capacity of CSO architecture services, including a brief description of real performance.

Optimizing the IT Business Green Supply Chain Utilizing Cloud Computing

Cloud Computing for Big Data Entrepreneurship in the Supply Chan: Using SAP HANA for Pharmaceutical Track-and-Trace Analytics the cost of managing IT service and cloud computing vs the benefit that the company will gain from applying it Cloud computing reduces the overall cost of IT management and enables organizations to adapt to rapidly changing business needs. With low initial investment and support for future growth, cloud computing is particularly appealing to startups developing a new technology that allows for detailed monitoring and tracking of the product through the green supply chain. Supplier Techniques develop programs to encourage new companies to re-use their cloud offers and display the value of cloud services on the market. XQS solutions show that a cloud-based analysis can support a large amount of tracking and tracking data generated in the pharmaceutical industry.

For example, tens of millions of records generate an XQS solution for large clinics. Using a table with more than 12.5 million tracking and tracking records, a virtual machine with 8 GB of memory, Intel Xeon Quad-Core, and a virtual machine are allocated to the database system, allocated to the logical processor (Chircu & Sultanow, 2014). The results show that the cloud-based HANA solution can overwrite SQL queries with multiple size factors and successfully performs a very complex query, for which MySQL fails due to a large amount of data. The business success of XQS will not be possible without effective business ideas; it is supported by access to effective, fast solutions and powerful cloud-based analytical solutions (Yen et al., 2014) We believe that their experience can inspire other startups to use cloud services to process large amounts of data (Chircu & Sultanow, 2014).

Green Supply Chain and Cloud in Airports

Coordination is a big job in airports that led to many complex problems. In order to achieve customers' needs and satisfaction, an idea of implementing a cloud with the green supply chain was introduced. Using a green supply chain as a service require an integrated cloud service that make it possible to share resources in one pool and work in a new way. Having an interface that eases the dealing with services and user needs while it is connected to the cloud will increase the efficiency and decrease the time wasted and resources. Also, it is easy to edit or change in the preferences and settings to adapt to new changes in the market or with the customers. The handling in the airport was done to the resources, companies and airlines sides. The handling for those three sides is difficult as they interior with each other and communicates. For example, airlines need to contact often the airport's recourses and staff for the flights and other information. Each airline has its system which makes it a hard job for airports to deal with that communication. Green supply chain system needs to coordination all those communications with high efficiency. The new approach helps this by having all the resources in one pool and making the services that are not used actively. The coordination of web services based on the cloud

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makes the inside resources arranged properly and the communication with airlines and other providers easier(Lingyun & Jiafei,2013).

As the standard coordination is not helping airports to deal with the massive amounts of outside links such as transportation, service companies, warehouse, customers and airlines. The need for universal united green supply chain integration with cloud becomes important. However, the fact that the cloud is still not a solid ground every one trust yet makes it harder to convince management to shift to such cloud services. Sharing resources and information will make it easier but in the same will raise some security flags. Such integration of green supply chain with cloud into web services is not an easy task that will require much work and there still many stability problems to start a trust and make use of it. The airport needs to organize training, and be aware of its information pool security (Bao et al., 2012) the case of breaching the cloud is another security concern that airports have to think about. The reliability of this integration in case of emergency flights or delayed is questioned. I think personally having a shared resource between many parts is a good positive thing if it is done probably because it will help with passing and forwarding the information and requests and it will raise the performance of the airport operations (Duan et al., 2013).

Handling the customer at the airport is a major operation. There are several levels of services done to customers. Bagging services are one of the levels that passes through many stages. Transportation of customer is another service. Loading the airplane and unloading it is an operation that got server steps. That service and operation the airport needs to handle it every day and resources are shared between different parts. The cloud and green supply chain integration will make it easier for the airport to manage such a flow of resources. The communication between the different parts and staff responsible for such ground operations will be way faster and accurate. Airlines can track the process online with real-time coverage. This benefits the airport and increases the reputation of it as well as the overall performance. The airport will first see it as a hard task to shift the whole system to one big system that has many integrated, connected parts. However, applying this kind of green supply chain as service integration with cloud will bring more benefits and will cut time wasted and communication expenses (Leukel et al., 2011).

Leveraging Cloud Computing to Enhance Green Supply Chain Management in Automobile Industry

The cloud computing providers offer their services according to different fundamental service models which are Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS).

In a cloud computing environment, SaaS will provide access to application software and databases, where cloud providers will manage the infrastructure and platforms to run the on-demand software which will charge the customers on a pay-per-use basis. PaaS provides a computing platform such as operating systems and related services on the Internet with the need of installing anything; it is sometimes called cloud-ware. The third service model is IaaS which represents the resources such as storage, hardware, servers, and networking components (Yinglei & Wang,2011).

In this document, to the extent that the automobile industry is concerned, the heart of the problem is how to build the set and convenient platform to improve E-commerce Green supply chain management. According to the above teaching, is adopted software as a service model for Cloud Computing facilitates the construction of SCM agile? The advantages of using SaaS can be summarized in the reduction of installation and maintenance costs since there is no need to buy a software license for each user which

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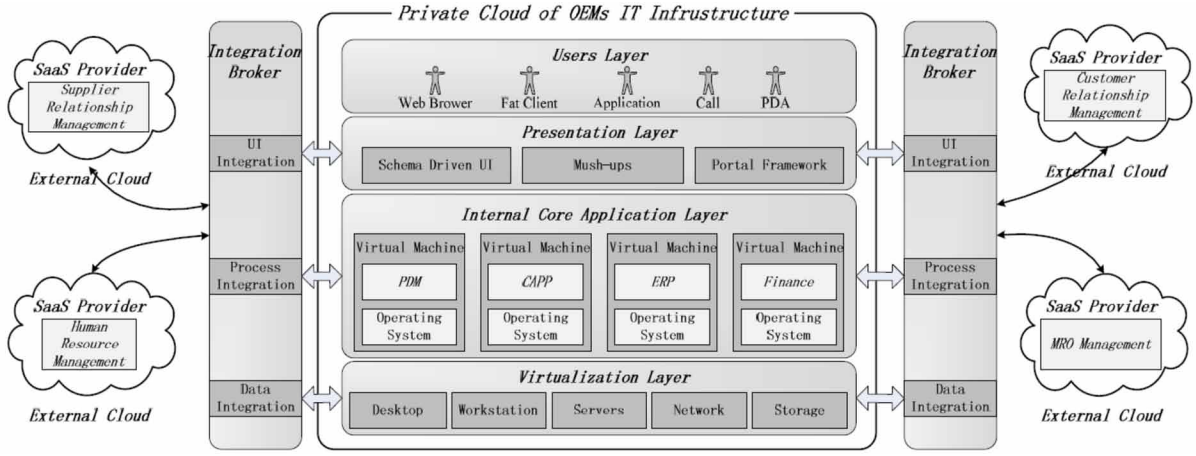
Figure 3. Cloud computing based reference architecture for SCM (Yinglei & Lei, 2011)



usually happens in the traditional model and also the maintenance cost is divided between the cloud users. SaaS can be seen as any other public service (electricity, water,) where the user pays on the amount of service he is taking which is called pay-as-you-go (Yinglei & Wang,2011).

For the small or new businesses, SaaS is the best implementation model since it reduces the initial business investment and can provide any service time which is not restricted in any place and by any software and patches upgrades.

In this part, reference architecture for Green supply chain Management (SCM) is introduced as shown in the figure below. XML-based Data Integration Middleware (XDIM) to address data integration issues between SaaS applications and on-premise applications (Hong-chang et al., 2011)

INFORMATION SHARING IN CLOUD COMPUTING

The Impact of "Cloud Computing"-Based Information Sharing on Green Supply Chain

The research presented in this publication uses both analytical and methodological approach through mathematical models to exploit real-time information sharing based on "Cloud Computing." The author has clearly provided type, limitation and limited orientation to the following terminologies with respect to the scope of is research and publication: Type of Information Shared, the pertaining definitions of Information Measurement, Quantitative and Qualitative Measurement of Information, Accelerating Physical Flow, Scope of Uncertainty in the Green supply chain, Building Cloud Computing Platform in Green supply chain (Makris et al.,2011).

The methodological approach is also provided to find the optimal solution for information sharing in a cloud computing scenario; the study uses a mathematics optimization model by including variables such as Product, Consumer (computed through Poisson Process, Auto Regression, ARIMA and Stationary Demand), Retailer and Manufacturer.

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The results of this study are very important to the green supply chain experts. It can be used as a benchmark for assessing the impact and value of cloud computing in the green supply chain. It is a cloud computing platform that facilitates and facilitates partners information services. For mid-sized and small businesses that cannot afford large hardware and software investments, the cloud computing platform will be the most effective and easiest way to exchange valuable information.

This research is a new information exchange model. However, there are not enough empirical studies and statistical analyses in this study (Celesti et al., 2011)

Adoption of Cloud Computing in Manufacturing Industry Green Supply Chains, a Hype or a Myth?

The research provided by the author is an effort to fill the knowledge gap of implementation of the Cloud Computing Technology (C.C.T) in the manufacturing technology and improve its green supply chain performance The Manufacturing Industry Collection has been selected because business in the industry is becoming increasingly robust IT, globalized, distributed and agile(Wang & Unger,2013).

Theoretical Framework

The main feature of cloud computing; according to a recent Merrill Lynch survey, Cloud Computing's "$ 160 billion in available markets is available, including $ 95 billion in acquisitions and productivity applications and $ 65 billion in online advertising. (Lindner et al., 2011)

There are three types of cloud deployment models proposed by the author:

• **Public Cloud:** It is characterized by being available from a third party through the Internet and is a cost-effective way to provide IT solutions, especially for SMEs.

• **Private Cloud:** Provides several of the advantages of a public cloud computing environment but is managed inside an organization. Private clouds supply greater control over the cloud infrastructure and are often compatible with larger installations (Wang et al.,2012).

• **Hybrid Cloud:** a collection of a public and private cloud —typically, non-critical information is obtaining (goods or a service) from outside or foreign supplier to the public cloud, while business-critical services and data are preserved within the control of the organization.

CONCLUSION

Cloud is a powerful way to perform different tasks within the company. Cloud computing brings new opportunities for many businesses to lower IT costs and administrative tasks. The shared resources pool makes it easier to connect different pieces of information for forecasting or sharing benefits. Cloud computing brings innovation and delivers a platform where different parts of the business can communicate and reach out. A green supply chain with using cloud can reduce lead time, and distribution of information is faster as all information is shared in real time united system. Cloud increase the communication channels accuracy between warehouses in Green supply chain as the system is updated online with the accurate amount of inventory levels and quantities. Customers' orders can be handled based in a fast interacted system with a low margin of errors and high availability. Security and maintenance of cloud computing is a side that will be handled by the service provider with a high level of expertise and data

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centers, so the company does not need to handle the IT side of such computing technology. This report discussed the different parts of cloud computing and showed some benefits of using it in the green supply chain and the company process in general.

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Demand Information Sharing for an Efficient Collaborative Supply Chain Planning

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ABSTRACT

Nowadays, many consumer goods manufacturers and retailers have understood the need to work together in order to elevate their performance. Such mutual cooperation, focusing beyond day-to-day business and transforming from a contract-based relationship to a value-based relationship is well received in the industries. Also, coupling information sharing in their collaborative setup is valued as an effective forward step. Moreover, advent of technologies naturally supports information sharing across the supply chain. As meeting consumers demand is the main aspect of supply chain, studying supply chain behavior with demand as a shared information makes it more beneficial. The chapter shall analyze demand information sharing in a two-stage supply chain with the performance measure being total cost in terms of profit. In order to quantify and understand better, the different levels of collaboration and their impact on the performance measure are analyzed using discrete event simulation. Arena software is used to simulate the required inventory control scenarios.

1. INTRODUCTION

1.1 Background

Most organization in order to stay competitive in the market, are gradually understanding the need to focus towards collaborating their different supply chain entities. Consistent higher profits and end customer satisfactions are the key driving factor to work towards an efficient supply chain and a collaborated supply chain is found to be an undeniable solution towards it (Srivathsan & Kamath, 2018). Among the many framework and strategies available for collaboration, Information Sharing within the supply chain is found to have reaped considerable benefits. Advent of technology like electronic data

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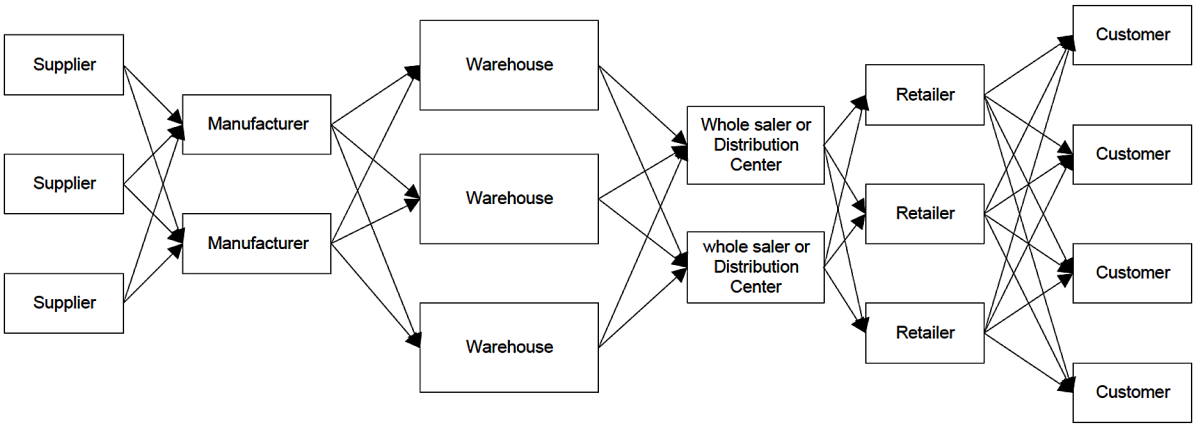
Figure 1. A typical supply chain (Source: Chang and Makatsoris, 2001)



interchange (EDI) has aided this concept naturally and mutually the supply chain members find it fruitful when integrated together. When it comes to collaborative techniques, organizations look to adopt tools like collaborative planning, forecasting and replenishment (CPFR), just in time purchasing (JIT) and vendor managed inventory (VMI) (Park et al., 2010). Once the collaboration strategy is identified the right information that could be shared up the stream is evaluated, as the need is to bring down on any risk and uncertainty faced so that profit and customer satisfaction could be expanded. When it comes to Information Sharing there are many information's that is beneficial when shared across the chain, but this chapter finds demand to be the most significant one among all the other information of share and it studies on how the profit enhances when demand as an information is shared.

Simulation is about replicating the real-world events over time. Simulation models have supported to understand the processes in many domains like healthcare, aeronautical, etc. and supply chain system is one among it (Rossetti, 2010). An inventory management in a supply chain system being a very complex process with the stochastic demand from consumers, and which follows more of either a discrete or a continuous distribution makes it an ideal entity to be evaluated via simulation. There are various classifications of simulations but a stochastic consumer demand in supply chain could be well studied in Discrete Event Simulation. Also, Arena being a popular simulating tool, is identified and used for modeling the supply chain collaboration models.

1.2 Problem Statement

According to (Chang and Makatsoris, 2001) the phrase Supply Chain Management phrase came up in the early 1990's and it was a process of integrating the supply chain members so that the goods are produced in the right amount, at the right place, at the right timed while in parallel satisfying the customer and keeping the cost to the minimum. The authors have represented a typical supply chain as per Figure 1. It consists of the various organizations involved from the supplier to the customer (Chang and Makatsoris, 2001).

(Nishat et al, 2006) suggest that a traditional supply chain system does not focus on waste elimination. They further share that traditional supply system meet uncertainties in its information or material flow by means of buffer goods which is met at higher costs and are very

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slow in its response to demand changes. The authors advocate that these issues are mainly due to the lack of collaboration and information sharing between the supply chain members.

From the typical supply chain network understanding from (Chang and Makatsoris, 2001), it is very evident that a supply chain network is highly complex in nature and if not managed appropriately could lead two main issues of high cost which in turn resulting in a low profit and unsatisfied customers which may basically lead to lost business/sales.

Also, from (Nishat et al, 2006) studies, traditional supply chain incurs high cost and lost customer satisfaction as they work as independent entities with no information sharing between them. This chapter will focus to demonstrate on how a collaborated supply chain, sharing information up the stream is able to minimize cost and increase on profit there by a traditional supply chain network could look to transform to an agile supply chain network.

1.3 Chapter Objective

The chapter's intent would be to demonstrate on the supply chain value increase when the level of collaboration is improved. With Demand as the control factor the profit improvement in the supply chain is studied. Discrete Event Simulation (DES) is the methodology applied and an analysis of the performance parameters based on the input controls is studied. The simulation models shall output supply chain performance with collaboration at three levels: No Information Sharing (NIS), Partial Information Sharing (PIS) and Full Information Sharing (FIS). Figure 2 depicts the levels of information share and the concept of information and material flow across the supply chain members. More details of the concepts are described in Section 3.4.

In addition, the models implemented would give a reasonable view on

- how traditional supply chain efficiency could be improved
- Profit improvement when Demand as an information is exchanged in advance

LITERATURE REVIEW

2.1 Introduction

In this chapter, existing research available on the objective is reviewed and discussed. Section 2.2 describes on how the supply chain collaboration has evolved and what is supply chain collaboration from researchers view. Section 2.3 discusses on Information Sharing on how it is seen as key enabler to supply chain collaboration. This section further elaborates on two topics, one being advance information sharing which helps in partial collaboration and the other topic is on vendor managed inventory which is aligned to a full collaboration scenario. Finally, section 2.4 brings out researches on discrete event simulation, since the approach has been embraced as a methodology to evaluate the objective.

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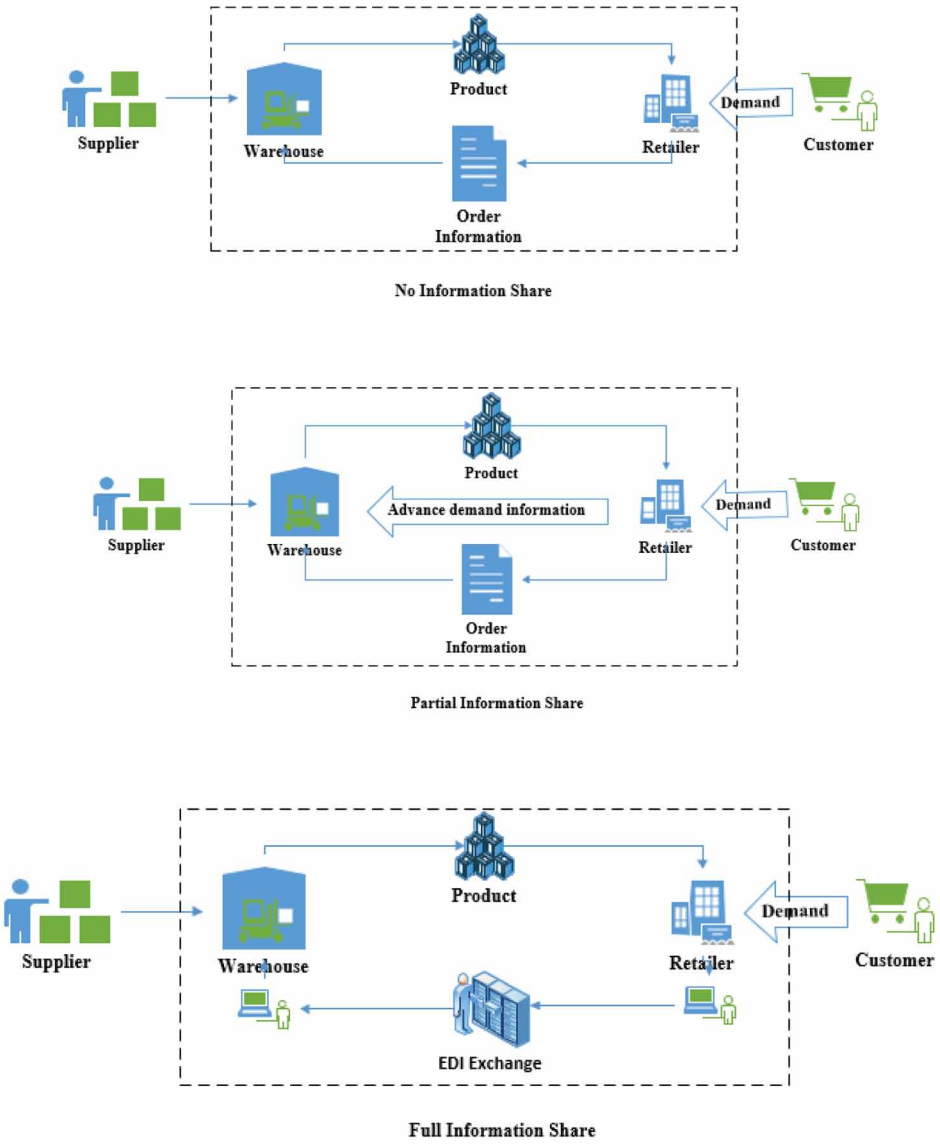
Figure 2. Information sharing scenario



2.2 Supply Chain Collaboration

Industries seeking to be ahead in the competitive world, have been evolving, by adopting new methodologies as early as from the nineteen or the twentieth century. In that era, work process integrations and optimizations were brought in by concepts such as lean production or just-in-time (Hopp and Spearman, 2008). After that supply chain collaboration has been the norm to share knowledge and to work integrated for an effective flow of products to the consumers (Caridi et al., 2005)

(Simatupang and Sridharan, 2002) in their research have defined supply chain collaboration as two or more supply chain member operating together by means of information sharing, mutually sharing

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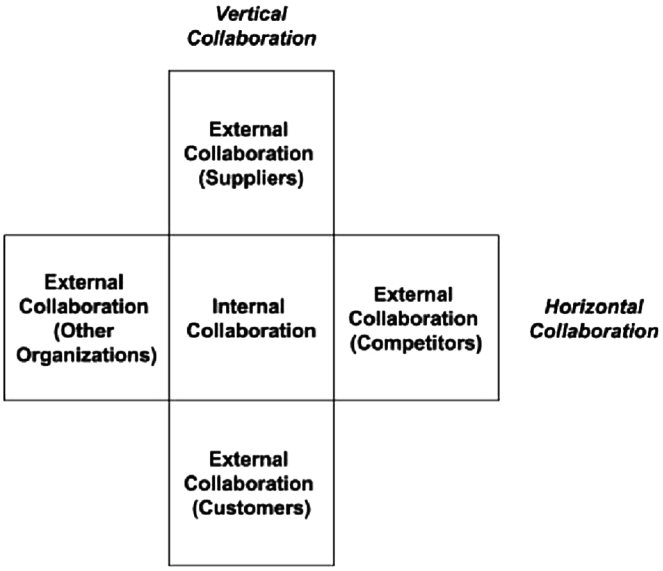
Figure 3. The scope of collaboration: generally (Source: Barratt, 2004)



benefits and looking to take joint decisions, so that high profits could be gained coupled together with greater level of end customer satisfaction.

Ideally there are different ways in which collaboration could happen and there are two distinct categories under which they could be encompassed is as per the review done by (Barratt, 2004). The first one is defined by him as the vertical vollaboration which includes the internal collaboration within supply chain members and external collaboration with suppliers or customers. He has described the second one has horizontal collaboration which includes the collaboration between the external competitors or other organizations (Barratt, 2004).

He has understood this flow from research done by (Simatupang and Sridharan, 2002) and has consolidated it in Figure 3 (Barratt, 2004). The chapter shall focus on internal collaboration which is a collaboration between the internal supply chain functions only.

Supply chain collaboration however is greatly challenged by the ever fluid state of the global economic conditions, which leads us to believe whether it is successful or not (Magnan and Fawcett, 2002). From the various surveys and case study interviews it is understood that very few companies have been able to integrate their supply chain successfully, also their study indicates that there are gaps between the theoretical and the ideal world (Magnan and Fawcett, 2002).

(Kohli and Jensen, 2010) had undertaken to measure the effectiveness of collaboration by studying the existing available literature and among their various inferences, a conclusion states that the effectiveness of collaboration is perceived to be high when there is information sharing between the supply chain members which leads the chapter to discuss more on information sharing further.

2.3 Information Sharing

(Simatupang and Sridharan, 2002) describe information sharing as the bidirectional flow of information between the supply chain members thereby giving all the necessary insight across the internal functions

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Table 1. Benefits of information sharing (Source: Lotfi et al., 2013)

No.	Benefits	Sources
1.	*Inventory reduction and efficient inventory management*	*[25, 37-39]*
2.	*Cost reduction*	*[25, 37, 39, 40]*
3.	*Increasing visibility (significant reduction of uncertainties)*	*[3, 6, 36, 39, 40]*
4.	*Significant reduction or complete elimination of bullwhip effect*	*[36, 39, 41, 42]*
5.	*Improved resource utilization*	*[25, 39]*
6.	*Increased productivity, Organizational efficiency and improved services*	*[25, 33, 39, 40]*
7.	*Building and strengthening social bonds*	*[39, 40, 43]*
8.	*Early problem detection*	*[39, 42, 44]*
9.	*Quick response*	*[39, 42]*
10.	*Reduced cycle time from order to delivery*	*[40]*
11.	*Better tracing and tracking*	*[40]*
12.	*Earlier time to market*	*[39]*
13.	*Expanded network*	*[39]*
14.	*Optimized capacity utilization*	*[39]*

and organizations. The authors also clarify that information sharing across the members lead to high customer service.

When it comes to what type of information that could be shared, (Lotfi et al., 2013) say that there are many types of information that can be shared within the supply chain like logistics, business, strategic, tactical and so on. The authors have also mentioned on few familiar types of information category such as 1) Inventory Information; 2) Sales Data; 3) Sales Forecasting; 4) Order Information; 5) Product Ability Information; 6) Exploitation Information of New Products; and 7) Other Information (Lotfi et al., 2013).

(Lotfi et al., 2013) have researched in detail and come up with a comprehensive table summarizing on the benefits of information sharing in supply chain. Table 1 is an extract from their research which gives us good view on the benefits reaped when there is information sharing in the chain.

(Yan et al.,2001) have demonstrated on how cost and inventory level reduces when the information sharing between the retailer and manufacturer is gradually increased. The authors have found that there is a pareto improvement which means that all members have benefited, and some members have strongly benefited in terms of cost saving when information share level is increased in steps.

(Gaur et al., 2005) have explored on how when demand has an information when shared up the stream in a two-stage supply chain model by the retailer to the manufacturer, lead to significant benefits like the safety stock reduction at the manufacturer side. This study implies that demand as information share is found to lead to substantial benefits not only to the manufacturer or retailer but also to the overall supply chain system.

2.3.1 Advanced Demand Information Sharing

This chapter has adapted partially on the concept of advanced demand information in scenario 2 of the partial information sharing system. So, reviews carried out on it are as below:

(Hariharan and Zipkin, 1995) has studied on the supply chain system performance when the customer demand information is received in advance. They have developed a model describing on it and the output

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analysis from the model is that the 'demand lead time' improves the performance of the system whereas the 'supply lead time' worsens it. Their study also exposes that this early information is a substitute for supply lead time and if managed well could reduce the safety stock and its corresponding cost in the supply chain system.

(Karaesmen et al., 2013) propose that if the advance demand information is handled effectively then the production/inventory performance would gradually increase. They have derived prepositions which tell us on which scenarios the advance information received could be meaningful and generate more benefit.

2.3.2 Vendor Managed Inventory (VMI)

(Marques et al., 2010) has studied the concept of VMI from concept to process and summarizes on the operational and collaborative element in VMI. According to the authors VMI is a supply chain integration where in the focus is on the continuous replenishment of the customers inventory. They also say that the partners share demand, requirements and constraints so they can have a shared objective.

(Yao et al., 2007) evolved a mathematical model for a single-vendor single-retailer VMI system. The demand information is assumed to be deterministic and the model carried an analyzes on the cost performance between a system with VMI and a system without VMI. Results reveal that the benefits are found to be spread between the buyer and supplier in an uneven manner. But in alignment to existing literatures, (Yao et al., 2007) found that implementation of VMI does reduce the inventory cost of the system thus rendering to be beneficial

2.4 Supply Chain Simulations

Enterprise Resource Management (ERP) which raised in the early 1990's evolved from the Material Request Planning (MRP) which is from the 80's. With the advancements in the information systems, MRP was able to be extended from a material tracking system to a more robust system including functions such as finance, human resource, project management etc. and this system was named as ERP (Chang and Makatsoris, 2001). The author has also researched that in the mid 1990's there were other software packages called supply chain management (SCM) systems or advanced planning and scheduling (APS). The SCM package was able to consider the factors and constraints impacting the delivery lead time and the response from it was quicker than when compared to the ERP system. The latter had a tough time to incorporate these concepts and the response time from it was in hours as it dealt with other functionalities and not concentrated with respect to supply chain optimization. From an academic research purpose both these software techniques are found to be costly (Chang and Makatsoris, 2001).

Managing a complex supply chain is very much necessary, so that a business can thrive successfully in today's scenario. Understanding the impact of a company's policy on the supply chain is not likely to be known before the role out of the policy. Here the supply chain simulation models facilitate to bridge this gap. Mathematical model or Analytical may have proven success in getting the results if at the system was simple but for real life complex problems studying the system via simulation would be the best. (Law and Kelton, 2000)

Discrete Event Simulation gives the opportunity to evaluate the operating performance in advance to the implementation of the actual system. What-if analysis could be carried out by the companies which aides them in efficient decision making with such models. Also, various operational alternatives could be identified from these models without disturbing the existing systems for a better policy decision (Chang

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and Makatsoris, 2001). The authors have also mentioned that prior to start of the supply chain modeling one should be aware of the entire supply chain. Also identifying the correct performance measure is vital. (Chang and Makatsoris, 2001).

For many year, analytical modeling has been the tool which has been used by management for supply chain, but it was more theoretical and did not solve practical problems. In this context (Swaminathan et al., 1996) has reviewed that Simulation has gained considerable attention and momentum. The authors have also identified various purposes when using modeling and simulation a supply chain system. The result of their research evidently depicts on how analytical results could be coupled with simulation and the model by itself is able to serve as a tool for decision making to industries. (Swaminathan et al., 1996).

(Kelton and Barton, 2003) have conveyed on how a carefully planned simulation could yield valuable information with any undue computational time or efforts. In the simulation context they have shared on some ideas, challenges and opportunities when looking to model and study behaviour patterns from the simulation models.

3. SOLUTION APPROACH

Simulation is not only about replicating a real-world scenario, but it is also a representation of the complex interrelationship as a function of time (Rossetti, 2010). The idea is that the required future system is achieved by a flexible model of the real physical system, coupled with its other system correlation modelled and validated with various scenarios until the predicted system is obtained. The process flow as shown in Figure 4 is adopted to meet the chapters objective. As shown, in order to simulate the foremost is to understand on the problem and to focus on a defined scope. In this chapter sections 1.2 and section 1.3 explains with respect to the step 1 and step 2 of the simulation process. Step 3 on System Understanding is to clearly formulate on the model decisions which support in ensuring that the simulation model is able to address the problem for a system considered. The system understanding for the model is researched and section 3.1 and section 3.2 gives a more elaborate description with respect to the decisions, assumptions etc.

Step 4 is on the simulation process. This is an iterative process which is further clarified on the process flow in Figure. 5. The flow defines on how the model is developed. It comprises of four stages: Model Conceptualization, Numerical Analysis, Model Implementation and Model Execution.

Model Conceptualization: Before the model implementation, with the system definitions set with respect to the inputs and outputs that require to be considered a UML design is formulated. A case diagram is first formulated to understand on the flow between the supply chain members consumer, retailer and warehouse. Section 3.2 describes the representation of the flow with respect to the three scenarios under discussion

Numerical Analysis: To evaluate the model conceptualized, theoretically a numerical analysis is carried out. An excel based macro sheet (Rossetti, 2010) has been adapted and updated to be used for various set of values to understand on the profit gain with collaboration. The outputs and results generated from the excel sheet is then compared with results from the model.

Model Implementation: With the model concept and the numerical analysis sheet, the adaption of the real system to the Arena simulation model is carried out. The level of detailing is ensured to be as close to the concept planned and for the inputs as designed from the numerical analysis sheet

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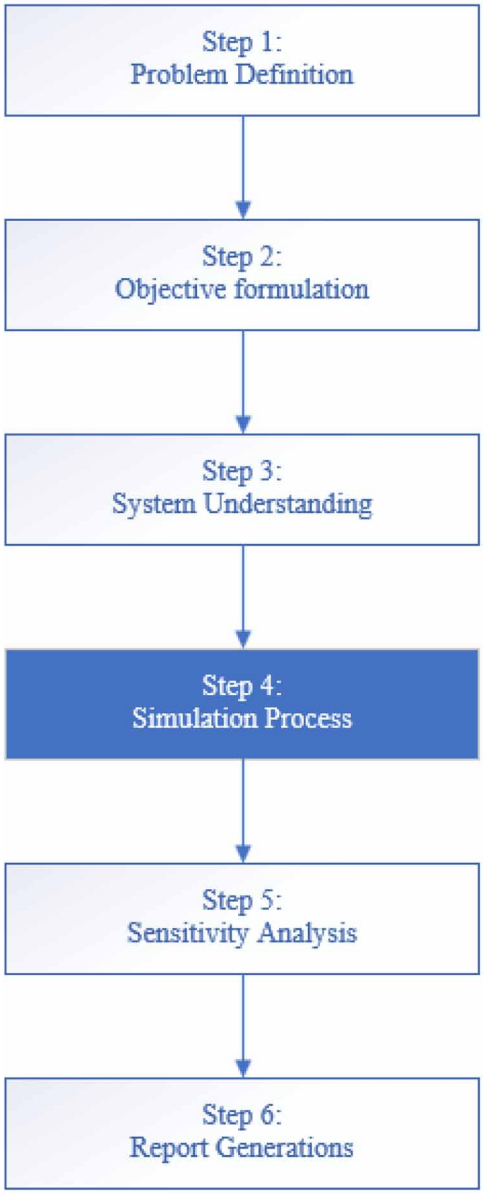
Figure 4. Solution approach



Model Execution: The developed model is then run for various demand values to understand on the profit gain with respect to the collaboration. The model goes through the verification and validation process.

Model Verification: This process is to ensure that the model is complete in all aspects intended and the output generated from it is close to the results generated from the numerical analysis sheet. The two main steps followed in this process are the setting up of the initial values and then observing the output for any variations. The input controls are varied in such a way that all scenarios are covered, also the best and worst scenarios are passed.

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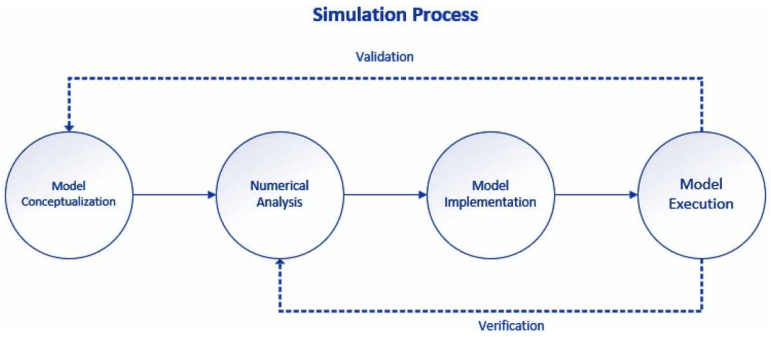
Figure 5. Simulation process



Model Validation: This process is carried out to ensure how close the model is to the real system. The retail world is considered here, hence the parameters and entity set are brought close to the retail environment. Many trials are executed via the process analyzer tool and the output is studied in relation to the actual system under discussion.

3.2 Inventory Model Decisions

In a supply chain a key aspect that establishes the health of the system is the inventory management. The financial upturn or downturn is very much determined by the inventory management decisions. It not only impacts a member in the chain, it affects in all layers. Hence maintaining an optimum value of inventory in a system supports the fiscal growth of the organization. In this chapter the decisions for an inventory model has been considered as per the Figure 6.

4.1.1 System Structure

System Structure is about the distribution structure of a firm. It varies greatly from industry to industry and based on the nature of the product and the consumer demand patterns. It could be considered as a system configuration which is a key and fundamental start point to an inventory model decision. Based on the storage location of inventory in a system there is Single Stage or Multi Stage system. There could be single or multiple products as output from this system. But the total quantity produced is strongly dependent on the production capacity, cost allocations and demand received from consumers.

Arborescent System are those systems in which each inventory location is served by a single source. Two networks in it could be the Serial State Network and the Multi Level Network (Figure: 7) (Hopp W J and Spearman M L, 2008)

In the serial system there are many stocking sites in series and each site serves only one destination site. Usually supply is also from a single source. In the multilevel arborescent system, the stocking sites may supply to more than one destination and there is multi level in it.

In supply chain the member close to the customer is said to be down the stream and the member close to the supplier is up the stream. Down the stream the demand information is understood from the consumers and produce is supplied as required to them. Upstream the procurement from the suppliers on raw material required is carried out so it can be used for manufacturing or distribution to the retailers

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Figure 6. Inventory model decisions

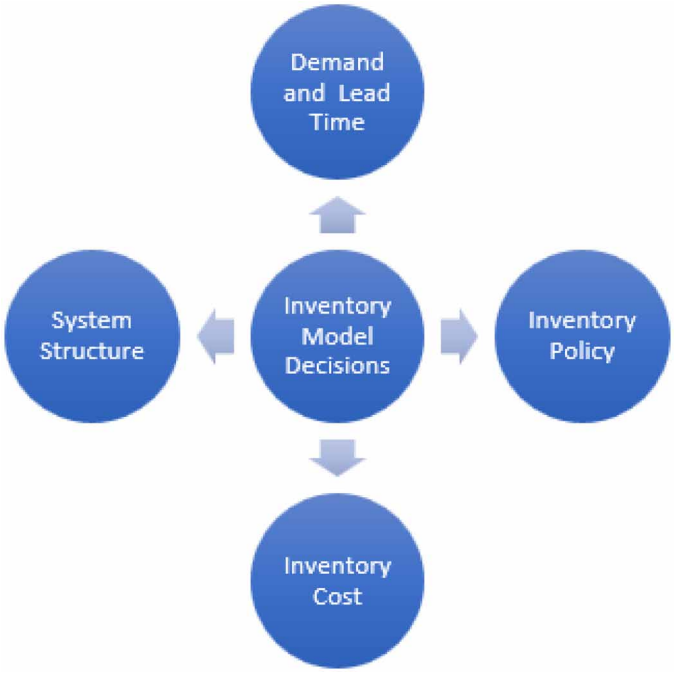

Figure 7. General arborescent systems (Source: Hopp and Spearman, 2008)

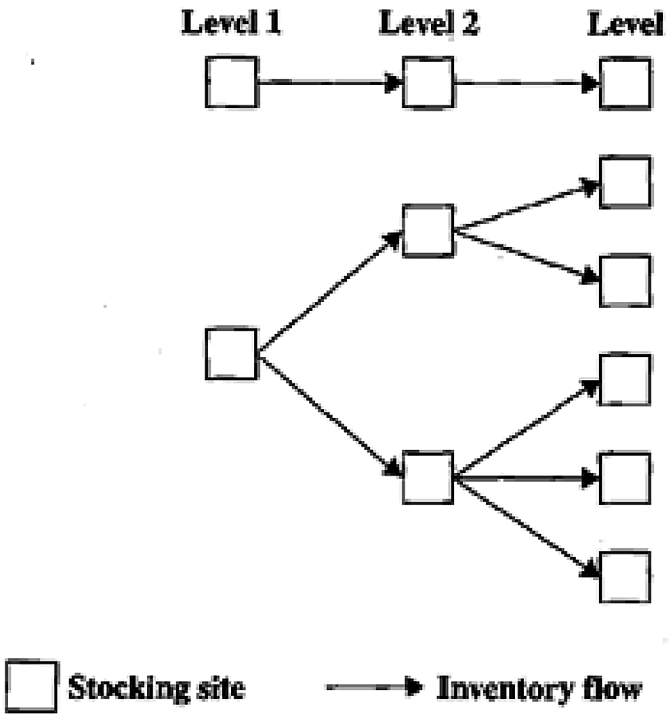

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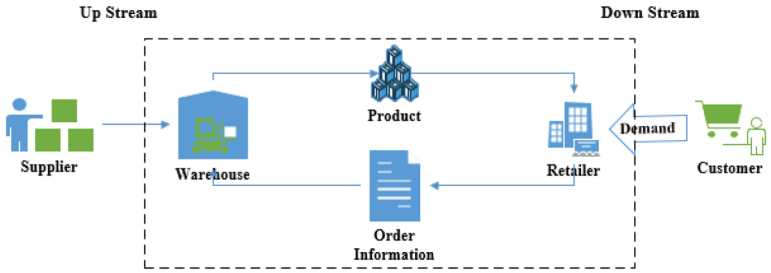
Figure 8. Arborescent series: two stage system



who in turn supply to the customers. Information flow in this supply chain is always up the stream and the goods flow down the stream. Figure 8 is represented to show clearly on upstream and down stream in a two-stage network system.

Also, the network system that this chapter shall consider would be the series two stage system as depicted in Figure 8. The goal of the chapter is to simulate and understand the benefits when the collaboration among the members is improved gradually, so the idea is that if initially in a series system the outputs are achieved exploring it further with multi level could be progressive.

4.1.2 Nomenclature

The below notation shall be considered to understand on the various cost calculations in the supply chain.

D – Demand rate per year
LT – Replenishment lead time in days
θ – Poisson distributed Mean demand during replenishment lead time
p(x) – Probability mass function

$$p(x) = \frac{\theta^x e^{-\theta}}{x!} \quad x = 0,1,2\ldots$$

G(x) – Cumulative distribution function

$$G(x) = \sum_{i=0}^{x} p\left(i\right) \quad x = 0,1,2\ldots$$

Q – Reorder Quantity (in units)
r – Reorder Level (in units)
h – annual holding cost ($)
b – annual backorder cost ($)
o – annual ordering cost ($)
I(r) – Average inventory on hand with respect to the reorder level r (in units)
IN(r) – Net inventory on hand (in units)
B(r) - Average back order with respect to the reorder level r (in units)
F(Q,r) – order frequency with respect to Q and r (in units)
S(Q,r) – fill rate with respect to Q and r (in units)
B(Q,r) – Average backorder number (in units) with respect to Q and r (in units)
I(Q,r) – Average On-Hand Inventory (in units) with respect to Q and r (in units)

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4.1.3 Demand Rate and Lead Time

In inventory management the two main sources from where uncertainty arises is from the Demand Rate and the Lead time. They are also a key factor in the decision-making process towards which type of inventory policy to consider.

Demand rate could be deterministic or stochastic. Deterministic demand is known demand and there is it is certain on what would be the quantity or when it would arrive.

Lead time is the time interval between the placement of order and receive of the placed order by the customer. Again, lead time here could be constant or varied. Usually lead time has a strong dependence on the supplier.

Demand could follow many different typed of distribution but two of the most important distribution available are the (discrete) Poisson Distribution and the (continuous) Normal Distribution. In Poisson distribution the mean time between arrival the arrival rate λ is exponentially distributed, so the exponential distribution is $f(x) = \lambda e^{-\lambda t}\ \lambda >= 0$.

Also, $\theta = \frac{\lambda LT}{365}$ which is the expected demand during the lead time.

Probability mass function

$$g(x;t) = \frac{\theta^x e^{-\theta}}{x!}\ x = 0,1,2\ldots \tag{1}$$

Cumulative distribution function

$$G(x;t) = \sum_{i=0}^{x} g\left(x;t\right) x = 0,1,2\ldots \tag{2}$$

The frameworks in this chapter considers a stochastic discrete demand which follows a Poisson Distribution and a fixed lead time.

Inventory Theory Base Formula:

(Zipkin, 2000) has analyzed the (r,Q) inventory model and has resulted in base equations when the demand rate is in a Poisson distribution. The analytical inventory formulas as provided by (Zipkin, 2000) are as below:

Poisson complementary cumulative distribution function:

$$G^0(x;t) = 1 - G(x;t) \tag{3}$$

Poisson first-order loss function:

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$$G^1(x;t) = - (x - \lambda t) G^0 (x;t) + (\lambda t) g(x;t) \quad (4)$$

Poisson second-order loss function:

$$G^2(x;t) = (1/2) \{[(x - \lambda t)^2 + x] G^0(x;t) - (\lambda t) (x - \lambda t) g(x;t)\} \quad (5)$$

4.1.4 Inventory Policy

With the demand being uncertain and random there are two significant models which could be suited. If in a scenario, random demand occurs the model in which inventory is replenished one unit at a time then the only issue is to determine the reorder point. The target inventory level set for the system is known as a base stock level, and hence the resulting model is termed the **base stock model** (Hopp and Spearman, 2008). The model in which the demand occurs randomly, possibly in batches, then here the inventory is monitored continuously. As per (Hopp and Spearman, 2008) when the inventory level reaches (or goes below) r, an order of size Q is placed. After a lead time of l, during which a stockout might occur, the order is received. The problem is to determine appropriate values of Q and r. The model we use to address this problem is known as the **(Q, r) model** (Hopp and Spearman, 2008). This thesis shall deal more with the (Q,r) model as the policy considered by the retailer and the warehouse follows this policy for satisfying the demand received from the customer.

(Q, r) inventory control policy

This inventory policy is a continuous review with backordering involved in it. The customer order information keeps coming in one at a time in some stochastic manner. To meet the demand as it arrives the order request is checked against the current stock availability in the system. If it is available, the customer order is relinquished immediately, and the stock availability is decreased by a count. But if stock is not available then the customer order is backordered in a que which acts on a first come first serve basis. The inventory position is checked every time when ever an order is met or backordered against the reorder point r to decided whether an order needs to be placed. If the inventory position goes below the reorder level r, then a re-order quantity of Q units is placed. This Q units ordered comes after a fixed time, which is the lead time LT from the supplier. After this time once the order is received the customer order as well the backorder as per the que is met.

In this concept there are three main inventory levels and a service rate to understand on. These terminologies are explained as follows

Net Inventory

This is the inventory on hand or the available stock at a unit of time without considering on the backorder. This inventory keeps decrementing every time a customer order is met and increments whenever a requested order is received. The net inventory is therefore understood as below:

Net Inventory = inventory on hand – backorder level

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Inventory Position

This represents the level of net inventory along with inventory in order. On a inventory level it is the actual position at that instant. It is represented as:

Inventory Position = inventory on hand – backorder + inventory on order

Since it has all the required inventory level interlinked, it becomes the ideal parameter to check against the reorder level to take a decision on whether to reorder or not.

Backorder Level

It is the number of units which are backordered as the inventory on hand is not available. It keeps incrementing till the order placed is replenished. It has an associated cost which is charged per unit time till it gets to serve the cost who is waiting on his backordered unit.

Fill rate

The term fill rate is associated to the stock out condition of the inventory. Stock out represents the duration of time that the system is in the out of stock situation. It is represented in terms of percentage and ideally the lesser the percentage the better is the performance of the system. Fill rate is just 1 minus of the stock out rate. It is the duration for which there is inventory on hand to serve the customer.

Fill rate - 1 – stock out

The average fill rate, backorder level and the inventory level in terms of Q and r has been deduced by (Zipkin, 2000) and it is given as below:

S(Q,r) – fill rate with respect to Q and r (in units)

$$\overline{SO} = \frac{1}{Q}[G^1(r\ ;\ L) - G^1(r+Q\ ;\ L)] \tag{6}$$

B(Q,r) – Average backorder number (in units) with respect to Q and r (in units)

$$\overline{B} = \frac{1}{Q}[G^2(r\ ;\ L) - G^2(r+Q\ ;L)] \tag{7}$$

I(Q,r) – Average On-Hand Inventory (in units) with respect to Q and r (in units)

$$\overline{I} = (1/2)\ (Q+1) + r - \lambda\ L + \overline{B} \tag{8}$$

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Based on (Zipkin, 2000) equations from (3) to (8), (Hopp and Spearman, 2008) derived the equations for the fill rate, average backorder level and on-hand inventory in terms of the backorder. These equations aid in bringing up an excel based inventory analysis sheet which has been extensively used in the numerical evaluation of the model. The base of the excel has been considered from (Rossetti, 2015) but the formula clarifications are discussed in this section.

S(Q,r) – fill rate with respect to Q and r (in units)

$$S\ (Q, r) = 1 - \frac{1}{Q}\ [\ B(r) - B(r + Q)] \tag{9}$$

B(Q,r) – Average backorder number (in units) with respect to Q and r (in units)

$$B\ (Q, r) = \frac{1}{Q} \cdot \sum_{r+1}^{r+Q} B\left(r\right) \tag{10}$$

I(Q,r) – Average On-Hand Inventory (in units) with respect to Q and r (in units)

$$I\ (Q, r) = \frac{Q+1}{2}. + r - \theta + B\ (Q, r) \tag{11}$$

4.1.5 Inventory Costs

Some of the financial parameters dealt in the thesis in order demonstrate on the total cost reduction is as described below:

Ordering Cost or Fixed Setup Cost (OC)

This cost is also referred as the replenishment cost and this cost is every time curred when an order is placed. It is the product of number of replenishment /Order Frequency carried out in a year and the replenishment cost factor associated to it. The order frequency as per (Ho and Spearman, 2008) is the number of orders carried out over a period. In thesis the period of consideration is for a year. Hence the order frequency and the associated ordering cost is as per equation given below by the authors

$$\text{Order Frequency } F\ (Q, r) = \frac{D}{Q} \tag{12}$$

$$\text{Ordering Cost (OC)} = F(Q,r) * o \tag{13}$$

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Holding Cost (HC)

All the cost that goes into storing of the inventory at a storage location is called the holding cost. It is usually the product of the actual inventory level held and the holding cost factor.

$$\text{Holding Cost (HC)} = I(Q, r) * h \tag{14}$$

Backorder Cost (BC)

The cost that is incurred every time when ever a customer order is not satisfied is called the Backorder Cost. It is the product of the backorder inventory level and the cost factor associated with the backorder. This cost factor in fact is a penalizing fee on not satisfying the requested customer demand.

$$\text{Backorder Cost (BC)} = B(Q, r) * b \tag{15}$$

Total Cost (TC)

The sum of all the above cost is the total cost. The total cost of the supply chain needs to be at the minimum so that profit could be improved. The information sharing model considers this total cost to be the performance measure component to understand on how the level of collaboration improves on the reduction of this total cost. This cost considers the ordering cost, holding cost and the backorder cost and its equation is given as below:

$$\text{Total Cost (TC)} = OC + HC + BC \tag{16}$$

4.2 Model Conceptualization

Three simulation models are developed as per the information level sharing. The model developed aligns as per the below key assumptions:

- The retailer and warehouse, each follow the continuous (r,Q) policy
- The Demand follows the Poisson Distribution Process
- Demand that is not met is backordered
- Replenishment lead time is fixed

According to the levels of information sharing the partnership collaboration for the three scenarios are as explained below:

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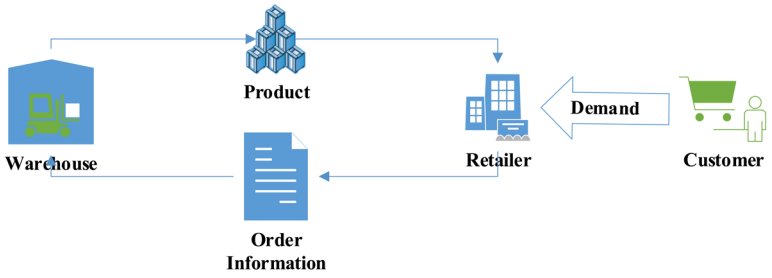
Figure 9. No information share (NIS)



4.2.1 No Information Share (NIS)

In this case there is no information sharing between the retailer and the warehouse and order coordination is missing as well. Both the supply members work independently in a more 'decentralized' manner. This system is more aligned to the traditional supply chain system and the decision making on demand is found to be self reliant. Figure 9 depicts the No Information case, here as shown the customer demand arrives to the retailer and based on this information and his on-hand availability of the stock the retailer raises order information to the warehouse. The warehouse similarly based on his available stocks he immediately responds to serve the retailer or raises purchase request with his suppliers, replenishes his stock and then further replenishes the supplier's inventory. Figure 9 depicts the flow in which the simulation model is developed. A two-stage network system which includes the retailer and warehouse internally and the customer or supplier at the external end is considered.

The detailed flow of the concept is as per Figure 10. The model is adapted from the simulated model developed by (Tee & Rossetti, 2003). The authors have considered a warehouse and n retailers in a two-echelon inventory system and simulated it to study the effectiveness of simulation models. This model has been considered as the base by this chapter and has been adapted to limit to a retailer and to include profit structure, so study on Information Sharing benefits could be achieved.

In the Figure 10. the order process at both the retailer and warehouse follow the (r,Q) policy which is leveraged from the works of (Tee & Rossetti, 2003). The authors have described that when an order is received then the system check the current inventory on hand if available the demand is immediately met, and on-hand inventory is decreased. If at all the stock is unavailable, then the entire order is backordered in a que system. Once the replenishment is received then as per first come first serve basis the backordered inventory is served. The inventory position at any point in time is the sum of the inventory on hand, inventory ordered minus the backorder. This inventory position is checked with the reorder point and whenever it fall below it the replenishment is ordered which arrives after the lead time.

4.2.2 Partial Information Share (PIS)

In this case the system is to a certain extent made coordinated between the retailer and warehouse. The warehouse apart from the order information from the retailer also receives the demand and the lead time of the product as shown in Figure 11, thereby aiding to reduce the lead time and meet the demand as expected by the customer.

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Figure 10. Process flow: no information share (NIS)

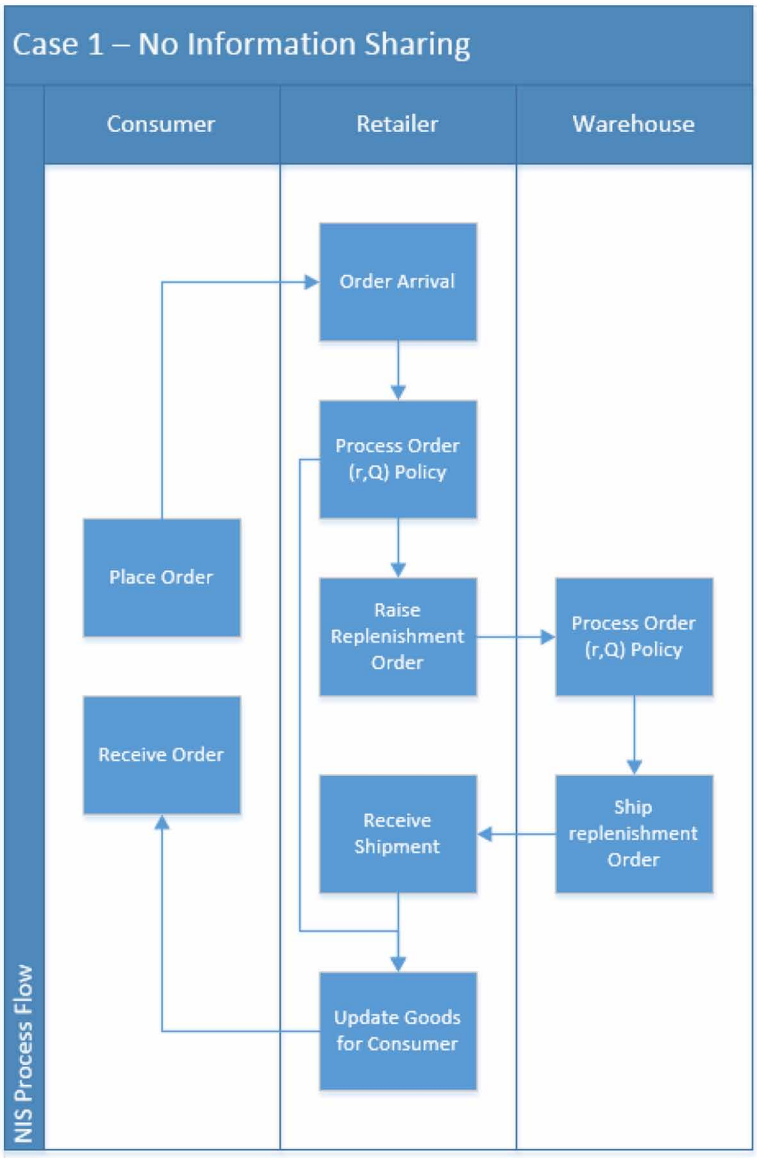

Figure 12 shows the concept of the Partial Information share level, in this case the customer provides the advance information on his demand and lead time to the retailer who in turn updates the warehouse regarding it. The base concept of the model is as per the analytical model developed by (Hariharan & Zipkin, 1995). The authors describe that when random customer order arrives, it arrives with a due date as to when the order goods are required to be delivered. This time between the order placement and goods reception by the customer is called the Demand Lead Time. So if a location has signed a contract for ADI, then the order arrives exactly l duration before the due date and if L is the supply lead time then as per (Hariharan & Zipkin, 1995) the system has a downstream lead time of (L-l). The other concepts are similar to that of the No Information sharing concept as explained in section 3.2.1.

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Figure 11. Partial information share (PIS)

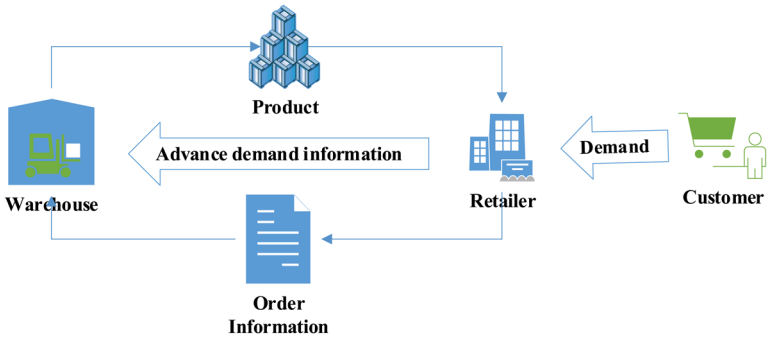
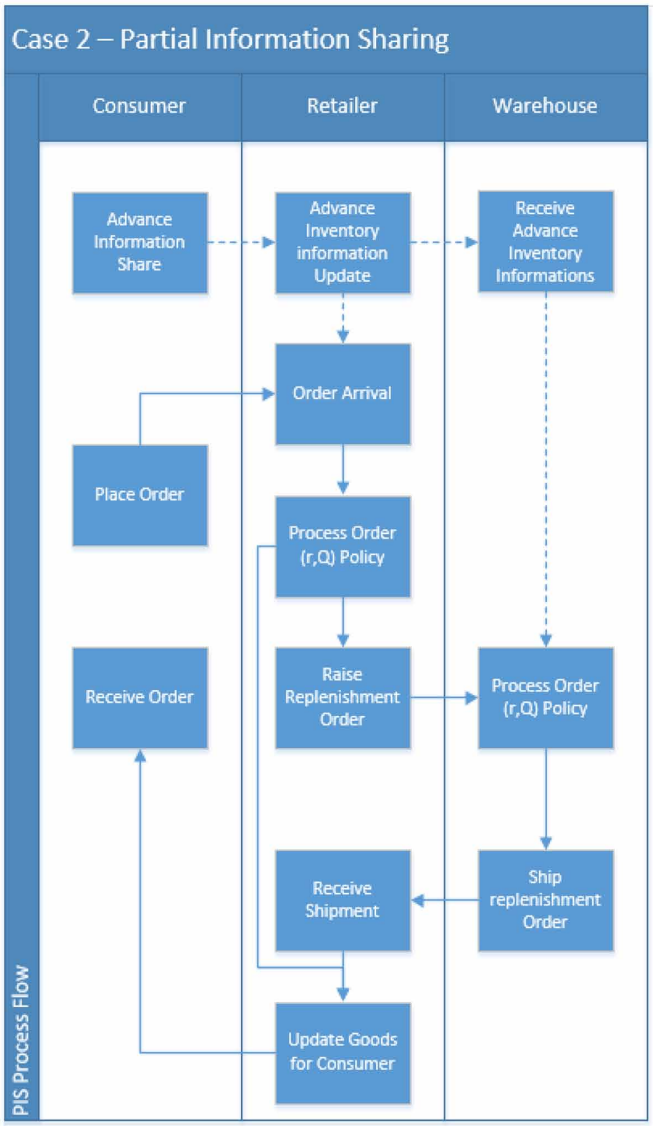


Figure 12. Process flow: partial information share (PIS)



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Full Information Share (FIS)

In this case, the two-stage inventory system reduces to a single stage inventory system. The retailer does not hold any inventory and transfers all demand processing information to the warehouse. As depicted in Figure 13, the retailer gets the demand from the customer and making use of the technology at hand, it updates immediately on the inventory information's to it. EDI (Electronic Data Exchange comes to play here. The warehouse similarly pulls up the information process's the request and supplies the product back to the retailer which is to be directly served to the customer. This is a Full information share concept adapted from the Vendor Managed Inventory system, where in the vendor takes full control of the demand information.

Figure 13. Full information share (FIS)

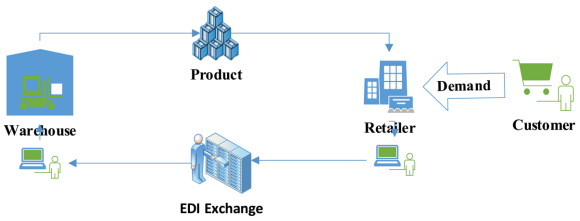
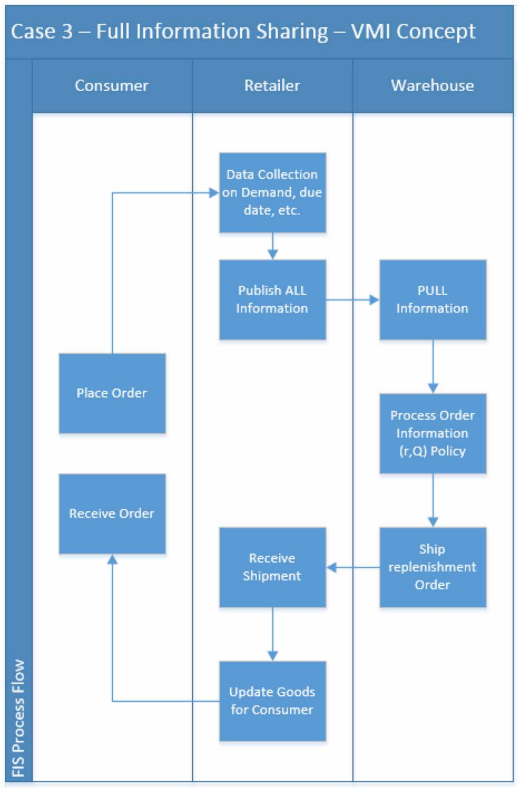


Figure 14. Process flow: full information share (FIS)



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As shown in Figure 14 the retailer publishes the inventory data received from the customer and the warehouse pulls the necessary information required for its processing and process the order and provides the information back to the retailer who in turn supplies the customer. As the upstream members take control of the inventory processing it is more a VMI aligned model.

4. NUMERICAL EVALUATION

In order that the models are evaluated a small and simple case scenario is considered and this scenario is applied to all scenarios of collaboration. Say in a two-echelon supply chain, a previous year data collected for a commodity has an annual demand *(D)* at a Poisson rate of 7 container units per year. The cost of a commodity container unit is \$150, and if an interest rate of 20 percent is applied, the annual holding cost *h* becomes 0.2(\$150) = \$30 per year. Let's consider that it takes a total of 45 days to receive a replenishment order. The purchase order for the commodity is set at about \$15, and the annualized cost of a backorder is about b = \$100 per year. The demand model follows a Poisson Distribution. The selling price of the retailer and warehouse is at 250\$ and 200\$ respectively and the warehouse makes a purchase from its suppliers at a cost of 150\$. The selling price and purchasing price have been considered so that analysis could be done from a profit perfect. This base scenario has been applied to all three levels of partnership and the output of the results has been documented as per the below sections. The 'rQInventoryModel,xls' spreadsheet consisting of macros to support in calculating the inventory levels has been adapted further to take care of profit calculations, ADI concept and retailer warehouse collaborations (Rossetti, 2010) .

4.1 Scenario 1: NIS

This 'No Information Sharing' scenario is the base with which the other scenarios are evaluated or analysed. Since this being the base, iteratively it has gone through many executions so that care has been taken to ensure that the actual values are closer to the theoretical values. Table 2 reflects on the theoretical deductions created before feeding the input to the simulation model for this scenario. For a demand rate set the optimal reorder point and reorder quantity at both the retailer (Rr and Qr) and the warehouse (Rw, Qw) is found and this is fed as controls to model. The expected response is also arrived at the spreadsheet so it could be evaluated from the model output.

After Table 2 has been generated, the input controls are fed to the models and to run multiple test cases the process analyzer tool is used. The model is repeated for 30 iteration and has a warm up period of 3600 days and a replication length of 39600 days. So, executing model for longer days and for various values of demand iteratively helps us to verify and validate the model better. The process analyser output is as shown in Figure 15. The responses are found to be close to the mathematical calculation developed.

4.2 Scenario 2: PIS

Here apart from the base scenario mentioned above there is an additional case assumed. The customer gives in advance that his order is going to be available at a time t and he would like his order to be met by 10 days from it. This information is available in advance to both the retailer and the warehouse. This from the previous scenario has a shortened lead time and from the mathematical model explained in

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Table 2. NIS: input and output parameters

Retailer Input Parameters								
D	LTr	Θr	h	b	o	SPr	SPw	
7	2.5	0.0479	30	100	15	250	200	
Retailer Optimum Response								
Qr	CR	Z	Rr					
2.646	0.769	0.736	0.209					
Warehouse Input Parameters								
D	LTw	θw	h	b	o	PCw	SPw	
7	45	0.8630	30	100	15	150	200	
Warehouse Optimum Response								
Qw	CR	Z	Rw					
2.646	0.769	0.736	1.547					

Control						**Response Expected**				
D	Qw	Rw	Qr	Rr	LTr	TCr	TCw	R_Profit	W_Profit	SC_ Profit
5	2	1	2	0	2.21	81.63	96.16	168.38	153.84	322.21
7	3	1	3	0	2.51	93.60	102.88	256.40	247.12	503.52
10	3	2	3	0	1.73	108.63	135.62	391.37	364.38	755.75
15	4	3	4	0	1.46	129.51	168.23	620.49	581.77	1202.26

Figure 15. NIS: process analyser output

	Scenario Properties				Controls							Responses		
	S	Name	Program File	Reps	vDemand	vQw	vRw	vQr	vRr	vRetailerLT	vWhsOnHand	TC_R	TC_W	Profit
1		1	14 : NI	10	5.0000	2.0000	1.0000	2.0000	0.0000	2.2000	2.0000	81.680	83.209	335.111
2		2	14 : NI	10	7.0000	3.0000	1.0000	3.0000	0.0000	2.5000	3.0000	93.742	101.140	505.118
3		3	14 : NI	10	10.0000	3.0000	2.0000	3.0000	0.0000	1.7300	4.0000	108.192	139.561	752.247
4		4	14 : NI	10	15.0000	4.0000	3.0000	4.0000	0.0000	1.4600	4.0000	128.871	128.080	1243.048

the Table 3. the inventory level is partially improved and backorder level is not there as the warehouse is prepared with this level of information share which aids him to serve the retailer and the consumer effectively.

With the numerical table complete, the model is fed values from it and the out put is observed. The model goes through iterations for various values until an optimized situation is reached for a demand value. Once the model is verified for a demand value as per the mathematical sheet then for various values it is run in the Process Analyser tool in Arena. Figure 16 shows the Process Analyzer output for the demand values provided to the model. The response is found to be close to the mathematical calculations.

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Table 3. PIS: input and output parameters

Retailer Input Parameters

D	l	LTr	Lr	θr	h	b	o	SPr	SPw
7	1.3	1.31	1.31	0.0251	30	100	15	250	200

Retailer Optimum Response

Qr	CR	Z	Rr
2.646	0.769	0.736	0.142

Warehouse Input Parameters

D	l	LTw	Lw	θw	h	b
7	35	45	10	0.1918	30	100

Warehouse Optimum Response

Qw	CR	Z	Rw
2.646	0.769	0.736	0.514

Profit Calculation of the Supply Chain for various Demand

Control						Response Expected				
D	Qw	Rw	Qr	Rr	Lr	TCr	TCw	R_Profit	W_Profit	SC_Profit
5	2	0	2	0	1.34	82.36	78.99	167.64	171.01	338.65
7	3	0	3	0	1.31	94.81	90.03	255.19	259.97	515.16
10	3	0	3	0	1.46	109.6	103.4	390.4	396.6	787
15	4	0	4	0	1.51	131.17	121.665	618.83	628.335	1247.165

Figure 16. PIS: Process analyser output

	Scenario Properties				Controls								Responses			
	S	Name	Program File	Reps	vDemand	vQw	vRw	vQr	vRr	vRetailerLT	vADI	vWhsOnHand	Profit	TC_R	TC_W	Supply Lead Time
1		2	27 : PIS.p	10	5.0000	2.0000	0.0000	2.0000	0.0000	1.3400	1.0000	2.8000	344.602	79.445	75.954	10.340
2		3	27 : PIS.p	10	7.0000	3.0000	0.0000	3.0000	0.0000	1.3100	1.0000	4.0000	524.931	90.325	84.744	10.310
3		4	27 : PIS.p	10	10.0000	3.0000	0.0000	3.0000	0.0000	1.4600	1.0000	4.0000	788.492	103.546	107.962	10.460
4		5	27 : PIS.p	10	15.0000	4.0000	0.0000	4.0000	0.0000	1.5100	1.0000	5.0000	1250.590	121.600	127.810	10.510

4.3 Scenario 3: FIS

In the complete information sharing, with respect to the numerical the retailer has no storage hence apart from providing the demand information to the warehouse it does not carry out any processing. As the two-stage system becomes a single stage the value assumptions hold good for the warehouse and for the retailer only the profit functions exist. Table 4 gives the mathematical evaluation in the excel sheet as in a single stage system.

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Table 4. FIS: input and output parameters

Retailer Input Parameters											
D	SPr	SPw									
7	250	200									
Warehouse Input Parameters											
D	LTw	θw	h	b	o	PCw		SPw			
7	45	0.8630	30	100	15	150		200			
Warehouse Optimum Response											
Qw	CR	Z	Rw								
2.6	0.769	0.736	1.5								
Profit Calculation of the Supply Chain for various Demand											
Control					**Response Expected**						
D	Qw	Rw	Qr	Rr	TCr	TCw	R_Profit	W_Profit	SC_Profit		
5	2	1	-	-	0	96.161	250	153.839	403.839		
7	3	2	-	-	0	129.82	350	220.18	570.18		
10	3	2	-	-	0	135.62	500	364.38	864.38		
15	4	3	-	-	0	168.23	750	581.77	1331.77		

Figure 17. FIS: process analyser output

	Scenario Properties				Controls			Responses	
	S	Name	Program File	Reps	vDemand	vReorderQty	vReorderPt	TotalCost_W	Profit
1		Scenario 2	3 : FIS.p	10	5.0000	2.0000	1.0000	96.609	403.391
2		Scenario 3	3 : FIS.p	10	7.0000	3.0000	2.0000	130.820	569.180
3		Scenario 4	3 : FIS.p	10	10.0000	3.0000	2.0000	136.611	863.389
4		Scenario 5	3 : FIS.p	10	15.0000	4.0000	3.0000	168.345	1331.655

As seen from the mathematical model computed, the retailer part does not exist, the warehouse does the complete processing and the values are observed for it. Feeding these inputs to the model and after repeated execution the model is verified against the model and then it is validated across various values of demand via the Process Analyzer tool and the Figure 17 depicts these outputs for the controls set for it.

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RESULTS SUMMARY

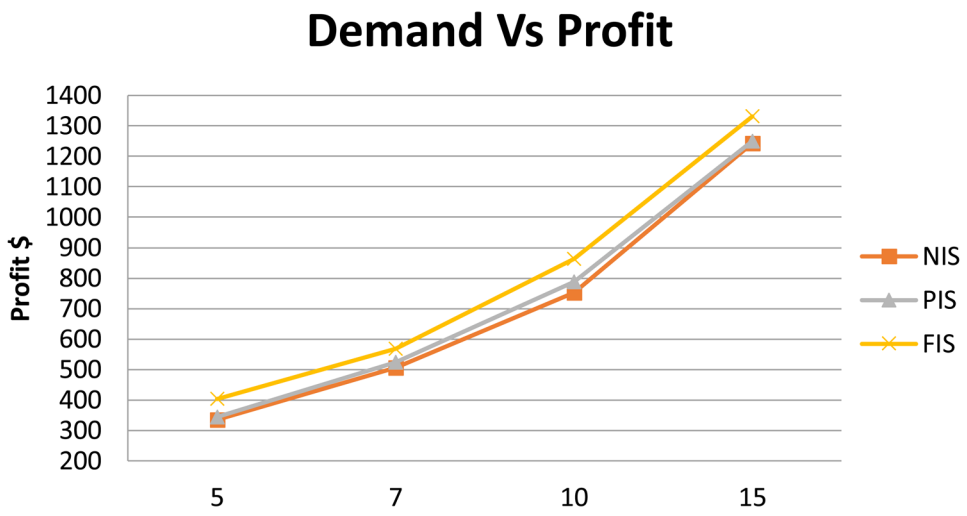
Now as the model has been verified and validated across the collaborations for information sharing. The outputs from it are consolidated as shown in Table 5. The No information sharing system since it is the traditional and ideal system this is kept as the base in comparison to the other two systems. The NIS could be the traditional system looking to transform to the partial or the full information system which are more agile versions in comparison to it. From the Table 5, on comparing the partial information system values to the no information sharing system an average of 3% increase is observed and similarly if the full information share is compared to the no information share then there is a 14% increase overall. This shows that the full information share is more robust compared to the partial information share.

Also, in Figure 18 the profit is plotted against various demand values and the performance of the three level of information sharing is analyzed. It can be inferred clearly that profit gain increases as the partnership or information sharing among the supply chain member increases.

Table 5. Overall partnership summary

Arena Simulation Results Analysis					
Demand Rate	**Profit $**			**Profit improvement % to NIS**	
	NIS	**PIS**	**FIS**	**PIS**	**FIS**
5	335	344	403	3%	20%
7	505	524	569	4%	13%
10	752	788	863	5%	15%
15	1243	1250	1331	1%	7%
			Average	3%	14%

Figure 18. Demand vs profit based on information sharing



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CONCLUSION AND FUTURE WORKS

4.4 Conclusion

This chapter attempts to demonstrate on how information sharing within the supply chain is found to be beneficial. Initially, based on a two-stage system comprising of an independent retailer and warehouse through modelling study the inventory control optimizations are executed. Later partial and full partnership is applied to the same two-stage system and result comparison to the initial base study is executed. The comparison results do show that there is a progressive improvement in the profit when moved from one level of information sharing to another. Thereby deducing that a collaborative supply chain is an efficient supply chain. Also, the simulations developed may aid traditional retailers looking to transform to an agile supply chain. It supports to experiment their supply chain transformation policy and to fine tune it as required before the actual policy is deployed for adherence.

4.5 FUTURE WORKS

In future, model could be expanded to a multi echelon system where in a warehouse serves multi retailers who in turn serve the customers at their end. The simulations currently developed could be a base from where it could be extended further to multi level of storage of inventory.

Also, Internal collaboration is what the chapter focussed on, but from the literature review carried out there are possibilities of horizontal collaboration that is collaboration with the competitors and other organizations and the vertical collaboration which is the collaboration between the customer and the supplier (Barratt, 2004).

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Chapter 24
The Comparison of E-Commerce Platform:
Selection of Key Analysis Factors

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ABSTRACT

E-commerce is a fast-growing part of the market. Dynamic development of internet technology and increase of mobile devices popularity gives this branch very good perspective. E-commerce is still young. Trends on it are set by a few websites, which created this market, and which provide still new and innovative solutions to their customers. However, there are still more and more underdogs, who decided to focus on particular niches. This decision gives them a possibility to reach specific audience. More and more entrepreneurs noticed this trend and try to use it for their businesses. However, due to the number of new websites, selection of the proper one is not an easy task. The main goal of the chapter was to select the key factors, which will help entrepreneurs to choose the best platform for their needs.

INTRODUCTION

Dynamic development of manufacturing Industry 4.0 is a result of some processes, for example: internationalization, information technology development and also hyper competition (Grzybowska, Łupicka, 2017). There is a huge growth of globalisation strategy on the market for a past few years. Products produced by a huge corporations are available almost all around the world. The biggest companies try to provide their products to as many markets as they can. To make it possible they use enormous budgets and the best marketing campaigns. Smaller companies, which analyze the possibilities of entering new markets are usually forced to looking for and investor or to take a credit for further operations. But in this case, the e-commerce platforms are the solutions as well.

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Modern logistics and e-commerce platform paradigm positively effects development of enterprises. Over time several types of logistics platforms have developed (Grzybowska, Gajsek, 2016). Logistics and e-commerce platforms represent a modern approach aimed towards fostering and facilitating logistics activities and business exchange. The e-commerce platform concept is one of the contemporary concepts in business strategies, which has attracted broader attention in the last decade. Cambra and Ruiz (2009) presented e-commerce platform as a source of competitive advantage. Despite the young age of existence, the e-commerce market is represented by a few renowned companies. In fact, these are the platforms which have developed the whole e-commerce market to a current condition. The biggest market players are for sure Amazon, eBay and recently developing, Chinese platform – AliExpress. These are the first choices for e-commerce customers.

Mentioned platforms are aware of a needs of a smaller market's players. In fact the smaller companies are also the customers of the three biggest platforms. Using services providing e.g. by Amazon makes reaching a new markets much easier and cheaper as well.

The following article is an answer to the entrepreneurs needs of choosing the right e-commerce platform for their businesses. The main goal of it is to specify the key factors for choosing the proper e-commerce site based on the individual needs. The following paper consist of three main parts. In the first part include all the necessary information about the e-commerce market. The second part provide more information about the key factors for choosing the right platform. This chapter is based on the opinions of the experienced e-commerce sellers. In the third part there are a lot more details about the key factors of choosing the right platform for the business. The whole article ends with the overview.

E-COMMERCE PLATFORMS: MANY CHARACTERS, DIVERSE FEATURES

A company success in distribution channels in current market is conditioned by a logistics and a quality of a provided services. Those actions are enabled with bearing the possible lowest own costs. Such functioning of the enterprise can be improved and become more effective by the development of IT system in logistics of the e-commerce, which is enabling unified way for the communication and the collaboration both inside and outside the enterprise (Frąś, Scholz, Olsztyńska, 2017). The e-commerce platform is the specific type of the Internet platforms. Based on the definition of the whole group of platforms, they enable Internet users to interact with each other. Usually they are used to exchange the services, content or products. The main gist of existence of e-commerce platforms is to provide to the customers possibility to buy products of services using the website as a tool. Nowadays, sellers are equipped with a lot of tools, which helps them monitor all the customers onsite behaviours. Using this tools in a proper way can help sellers increase their revenue instantly. It is all about providing the customers the things they really need. Together with the e-commerce market development, more and more markets decides to put all the shopping processes into the Internet. They recognize huge dormant potential of this solution. The opportunity of providing your products to the customers overseas gives your business a chance to a rapid growth. Not only the sellers see a huge potential of e-commerce market, but so do a developers. On the e-commerce market there still more and more solutions for every business needs. Depending on the features we can differentiate following types of platforms:

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- **Huge markets:** This type of platforms leap off the page by copying assortment of the physical stores. Using a cross-channel sales create a new opportunities for both sellers and the customers. Customers can validate the products in the physical stores, than think about the buying process again in home and order products via e-commerce platform. Huge advantage of e-commerce platform is that they usually provide products of many brands. It's very comfortable for customers, who can buy a diverse products and receive them all in one package. Another cutting edge of this solution are lower prices. E-commerce platforms do not bear the cost of employees of physical shops. The main factor of choosing this kind of e-commerce platform is assortment, which is as the same as in the stores in shopping malls.
- **Malls:** The assortment of this kind of platforms is as wide as the 'Huge markets' assortment, however the subject who provides good differ them or mention movable markets (Grzybowska & Kostrzewski, 2016). In the first case, products are provided by the companies which are also the owner of the particular platform. In the second case, products are provided by smaller or bigger companies, which are using the platform as a sale tool. This companies provide produced by their brands and are also the final suppliers. In this type of e-commerce platform owner of it provide to its' customers (sellers) a tool, which help them reached a new clients. The business model of such solution based on the fees, which owner of platform charge for every transaction or on the subscription. In this case, the owner of the e-commerce platform does not own any of the listinged products. He simply provide a tool for exchanging money for products. The key advantage of this solution for seller is that do not have to reach potential customers by themselves. Similarly to the first type of e-commerce platform, creating a community towards the platform is the main challenge for the platform owner. It can help the platform grow bigger and more dynamic.
- **Special offers:** This type of e-commerce platforms based on the competitive edge of the owner. The more market share it has, the more customers platform can reach. It works for sellers, who on the one hand provide cheaper products to final customer, but on the other hand they just use website as a tool. It means, that they do not have to realize any marketing campaigns, cause is all on the side of the platform's owner. As it was mentioned above, sellers provide cheaper products, but the discount they offer is equal to all the marketing operations they would need to bear.It works for customers as well. They receive cheaper products of the highest quality. The platform's owner in this case act as an agent between sellers and customers. It's main role in this scenario is to build community around the website.The more people owner attract, the more products they buy, the biggest its competitive edge is. Another factor, that can help owner reach more customers is extensiveness of provided services. Nowadays, customers can go through the whole shopping process using one tool. After making a decision which products they should buy, customers are redirecting to a third party website, where they can pay for their order.
- **Vertical market:** This types of platforms based on the specific niches of the market. One of the recent trends on market is to provide to customers only small group of products, but as specialized as they can be. Processes that in the past was provided by one company, nowadays, are diversified into a few subjects. This trend can be seen not only in the e-commerce, but also in the shopping malls, where there are more and more highly specialized shops. Providing such highly specialized e-commerce platform can result in providing to customers bigger group of products, cause they do not have to focus only on one brand. It is said, that this types of platforms is the future of the whole e-commerce market. Nowadays, customer are looking for a highly specialized solutions for

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professionals. This type of platforms, which are created by people experienced in a certain niche will reach more customers. This will eventually resulted in takeover of the e-commerce market.

- **High quality online auctions:** This relatively new solution is being more and more popular. Business model of it based on comparing online auctions and strategy game, which result in attempt to buying high quality products for as low price as possible. However, in this case, potential buyers agree with the risk of going away with anything. There are more and more dedicated solutions for this type of platforms arising on the market. Each of them tries to step out from the competition. One of mentioned solutions is to build community around of it, which was described in one of previous paragraph.
- **Connectors:** In spite of wide range of information concerning products or services, finding the platform, which fulfill all our needs is tough. This is a reason, why connectors has been created. This type of platform collect wide range of information about all issues connected with all e-commerce platforms from its database. Opinions and informations are provided by the customers of mentioned websites and this is the reason, why this type of platform are so popular. Before buying a desired products on particular website, customers can check others' clients feedback about shipping policy, quality of products, fulfilling the order etc. This solution has however also some defects. Nowadays, when there is a sharp competition in every market niche, companies can do everything to reach a potential customer. This type of platforms give such companies opportunity to provide some negative feedbacks, which do not have to be true. This kind of operations affect customers opinion, which can lead even to bankruptcy.
- **Facebook E-store:** Despite the fact, that social media platforms like Snapchat or Instagram are getting more and more popular, Facebook is still the biggest one on the market. One of the newest solution provided by this platform is e-store for Facebook Business Profile. With this tool, companies can list products on their Facebook fanpage. Choosing desired products link directly to company's e-store. This solution is a great opportunity to entrepreneurs to use all the potential, which Facebook community provide.

Choosing the Comparative Analysis' Key Factors

Based on the questionnaire filled by an experienced e-commerce sellers, the three main groups of factors were detailed. They include all the most important criteria for e-commerce platform assessment.

The first group of factors (Table 1) are the economic ones e.g. monthly subscription, selling fees, payment fees, shipping cost to final customer, shipping cost to logistic center, regulations about payment, warehousing fees. This group provide key informations about potential profit, that company can get. In the calculation process of weighted average of all the factors, this group of them received the highest weight. To exist on the market, every company has to generate profit. This is why business approach was the most important while setting weights of each factors' group. The following group of factors has the biggest impact of the company's profit, so it received the weight of 0.4. The first factor from this group is "Monthly subscription". A lot of platforms using this type of fees as their main profit source. The essence of such solution is receiving cyclical payment from the seller for a certain sum. Sellers are charged for a specific kind of services performed in the certain time. The range of assessment vary between 1 and 3, where all the notes are integers. Platform receive particular note if:

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1. Monthly subscription cost more than 200£;
2. Monthly subscription cost more than 100£;
3. Monthly subscription cost less than 100£.

This is one of the most important factors, which has a real impact on the company's profit. It's weight is set at 0.2.

The second factor of the following group is "Selling Fee". This type of cooperation between platform's owners and sellers is even more popular than monthly subscription. It's common that sellers have to pay both. This cost however appear with every transaction. Sellers need to pay fees which are set in advance and usually vary between 10% and 20%. The stronger company's position on the market is, the lower fees it can negotiate. This solution can be a win-win strategy for both sides. On the one hand, sellers can bear lower costs of selling their products via platform. On the other hand, platforms' owners are aware of the biggest sellers' potential. When they agree for cooperation at lower fees, they know, that due to economy of scale they'll earn more. In spite of lower individual profit, their overall profit generated by thousands of sold items will be much higher. Platforms can receive one of the following notes:

1. Selling fee is higher than 15%;
2. Selling fee is higher than 12%;
3. Selling fee is lower or equal to 12%.

To pointed out particular notes the terms of cooperation for each platforms were used.

This factor is as important as the first one, so the weight of it is as the same and is equal to 0,2.

The next important factor is "Payment fee". Providing complex solution is very tough and very challenging. Developing every issue by yourself take a lot of time and require wide range of knowledge. This is why so many of developers decide to use some of third party solutions as well. One of this solutions is processing of payment. There are a few companies which specialize in such operations and can provide reliable and safe software. Their charge seller as well, receiving a part of the whole transactions. Usually, the fees vary between 0.5% and 2.5%. The scale of notes for this factor is as following:

1. Payment fee is higher than 2%;
2. Payment fee is higher than 1.2%;
3. Payment fee is lower or equal to 1.2%.

There are more and more solutions of this type on the market. However, there are only a few, which are the most popular e.g. PayU, PayPal and smaller once, which operate only the specific area e.g. Przelewy24 in Poland.

Nowadays, it is common to send products down under. Seller using their own e-commerce stores needs to care about everything by themselves. They need to pick the right products, pack them properly and send them providing the right address. A few e-commerce platforms' owners noticed this opportunity to growth such solutions in their companies. They provide services of warehousing sellers' products, which after the sale process is completed are pick, pack and send to the right customers. This solutions is an outstanding logistic masterpiece and a great opportunity for both sellers and platforms' owners. On the one hand, sellers can send their products the every country where there is a warehouse of a particular e-commerce platform. This means that they can reach customers all around the world. On the other hand,

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platforms owners have an insight into all the processes that are done using their tool. They can used it to provide to customers new products, that they exactly need. The range of notes is presented below:

1. The shipping costs to final customers are paid by sellers;
3. The shipping costs to final customers are paid by platforms' owners.

In this case the note '2' is missing. It's because on the market only two presented options exist. One of them is beneficial for sellers and the other one - for platforms' owners.

Sales processes, which are done via Internet are still developing very fast. More and more customers decide to buy things using this sales channel instead of traditional one. It's more comfortable, but also cheaper. Entrepreneurs are aware of this trend and invest more money to develop their e-commerce marketing solutions as well as sales solutions and logistics. The biggest market's players provide their customers, who in this case are seller, a lot of logistics solutions for their businesses. One of them is a program, which was implemented by Amazon at first. Sellers receive possibility to send their products to warehouses operated by platforms' owners. When order appears products are send to the final customers directly from the following warehouse. This is great solution for sellers, who do not have to have a logistic centers by their own. Logistic processes can be paid by platforms owner or the sellers. This cost is another economic factor, which was took under consideration in the following papers. The range of notes is provided below:

1. The shipping cost to logistic center operated by platforms owners are covered by sellers;
3. The shipping cost to logistic center operated by platforms owners are covered by platform owners.

As the same as in the previous case, the '2' note is missing, due to market order.

A lot of entrepreneurs run their businesses on the basis of VAT invoice. The date of payment is usually specified at this type of document and can vary between 30 and 90 days. Using the e-commerce platforms as a tool they also receive such invoices. In this case however, payment date is set by seller, but in most cases it need to meet a platform requirement. Cash flow is one of the most important things for entrepreneurs, so is the following economic factor. Sometimes entrepreneurs need to receive their money faster, due to some urgent operations. The gist of the following factor is a flexibility of setting the payment date and the range of notes were provided below:

1. The payment can be made only in a strict dates;
3. Sellers have a possibility to withdraw their money in any moment.

This is a factor, which sometimes determine the business future.

There are a lot of processes in the mentioned logistic centers operated by platforms owners, which generate huge costs. Sometimes sellers bear this costs. Warehouses operated by platforms' owners are designed to be a cross-docking centers. Using this solutions costs of warehousing is lower. This is why the best sellers, who sell their inventory relatively fast, are invited to special logistic programs. At the same time, sellers who do not meet requirements are charged additionally. In the assessment process the following notes were used:

1. The warehousing costs are beared by sellers;

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3. The warehousing costs are beared by platforms' owners.

The second group of factors (Table 1) which influenced on the e-commerce platforms assessment are the technical factors e.g. integration with third party solutions, ease of adding and editing products in platform's system, advertising tools, bulk editing processes, sales analytic tools, customer service tools, reliability of platform, managing processes. One of the key factors in this group is possibility of integration third party solutions including e.g. ERP. This kind of software, which helps companies managing all their processes, are really helpful for them. This solutions at the same time create possibility to growth for the companies. Using Electronic Data Interchange expedite all companies processes, which lead to better and faster flow of materials and informations.The range of notes is provided below:

1. The integration with third party solution is complicated;
3. The integration with third party solutions is not complicated.

Ease of adding and editing products in the platform's system is also very important factor. Sometimes companies sell thousands of products and adding each of them individually would take a years. Fortunately, platform's owners care about how fast and intuitive their systems are, which can decrease all the processes drastically. In such processes workforce cost as well as warehousing costs needs to be taking under consideration. The faster mentioned processes are completed, the more money entrepreneurs can save. The range of notes is provided below:

1. The process of adding and editing products is complicated and time-absorbing;
3. The process of adding and editing products is easy and fast.

Every e-commerce solution needs to be supported by marketing processes. Almost every platform provide adequate tools to promote products. Usually such tools are based on popular e-commerce strategy PPC (Pay-per-click). The first step in this kind of advertising is to choose the right product to promote. Then, the budget of the campaign and the the target audience needs to be set. The following step is to choose the right keywords, that customers are using. The companies bear the cost only when the customer click their campaign. Their do not pay for setting and managing the campaign. The range of notes is provided below:

1. The platform's owners do not provide advertising tools;
2. The platform's owners provide advertising tools, but only the basic once;
3. The platform's owners provide well-developed advertising tools.

Like mentioned above, some companies provide to customers thousands of variants of products. It is impossible to manage all of them individually. This is why platforms provide tools for bulk processes. With this tool companies can implement changes in an easier and faster way. The range of notes is provided below:

1. Platform does not provide any tools for bulk buy processes;
2. Platform provide only basic tools for bulk buy processes;
3. Platform provide well-developed tools for bulk buy processes.

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Table 1. Group of factors

Group of factors	Assessment's group weight	Particular factors	Particular factor's weight
ECONOMIC	0.4	Monthly subscription	0.2
		Selling fees	0.2
		Payment fees	0.05
		Shipping costs to final customers	0.1
		Shipping costs to logistic centers	0.05
		Payment regulations	0.2
		Warehousing fees	0.2
TECHNICAL	0.3	Integration with third party solutions	0.1
		Ease of adding and editting products	0.2
		Advertising tools	0.1
		Bulk editing solutions	0.05
		Sales analytic tools	0.1
		Customer service tools	0.15
		Reliability of platform	0.2
		Managing processes	0.1
DEVELOPMENT & COMPETITIVE	0.3	Numer of unique users	0.3
		Innovative solutions	0.1
		Customization	0.1
		Marketing processes performed by platform's owners	0.15
		Ease of controlling admin account	0.1
		Customer service standards	0.15
		Partner Programs	0.1

Source: Self-reported data

The main goal for every company is to generate profit. Nowadays, almost every e-commerce platform provide specific tools to analyse sales processes and customers behaviour. It is great solution for sellers who can use only one website to control the most important issue for them. Stats provided by platforms' owners are developing very fast, so the companies have a deep insight of what is working on their sites and what does not. The range of notes is provided below:

1. Platform is not equipped with sales analytic tools;
2. Platform is equipped with sales analytic tools, but they are not well-developed;
3. Platform is equipped with well-developed sales analytic tools.

Every company which exist on the mark needs to gain some competitive edge. Recently, almost every company tries to meet their customers individual needs. Customer service is one of the main issues, that can convince customers to choose particular brand. There is more and more employers in this area

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of almost every company. Their task is to provide services at the highest level. Platforms' owners also tries to provide the highest quality services. This is why they provide specific tools for managing contact with customers or CRM. The range of scale is provided below:

1. Platform does not provide tools for managing customer relations;
2. Platform provide only basic tools for managing customers relations;
3. Platform provide well-developed tools for managing customers relations.

All the factors listed above are very important for entrepreneurs while choosing the right e-commerce platform for their businesses, but there is one factor, which is more important than the others - reliability. Gaining customers is a difficult process, but persuading him to use this solution more than one time is even more difficult. This is why platforms can not crush. If they do, the can never regain customers. The range of notes is provided below:

1. Platform works well, but it crushes from time to time;
3. Platform is reliable and do not crush ever.

Using third party solutions can be very complicated and expensive for some companies. ERP is one the best solution for managing every process in company, but it is extremely expensive. This why it is so important it is for smaller companies to receive such solution as a tool in a platform's system. Usually it is provided as a free tool which can help use companies resources in a better and more effective way. The range of notes is provided below:

1. Platforms do not provide tools for managing products and processes;
2. Platforms provide only basic tools for managing products and processes;
3. Platforms provide well-developed tools for managing products and processes.

The last group of factors (Table 1) taking under consideration in assessment of e-commerce platforms is group of developmental and competitive factors, which includes: the number of unique users, innovative solutions, customization, marketing processes performed by platform's owners, ease of controlling the admin account, customer service standards, partner programs. The most important factor in this group is the number of unique users. This factor determine how many customers can sellers reach. The more customers can sellers reach, the more products they can sell. As mentioned in previous paragraphs, the main goal for every company is to maximize their profit. This is why sometimes even the best tools and solutions are not as important as the number of unique users. The range of notes is provided below:

1. Less than a million unique users;
2. Less than a 10 millions unique users;
3. More than 10 million unique users.

There are more and more e-commerce platforms on the market. Everyday it can be seen that the new one is launching. Some platforms focus on providing to the sellers possibility of listing any product they want, while the others focus on providing the best solutions for particular niche. They all are looking for a competitive edge which will stand them up. This why it is so important it is to provide still more and

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more innovative solutions to customers. All this processes can help reach more users, which is the most important issue for platform's owners. The range of notes is provided below:

1. Platform does not implement innovative solutions;
2. Platform implement some new, innovative solutions, but similar to the competition's solutions;
3. Platform provide truly innovative solutions.

E-commerce platforms have two groups of customers. The first group include the final customers. These are the platform's users, who buy products as a final customers. The second group include sellers. This group is as important as the first one. As mentioned above there is more and more e-commerce platforms on the market and each of them tries to provide as good and innovative services as possible. This is the reason why seller do not have to stick to only one website. If they find the other solution better they can switch to it in every minute. Platform's owners are aware of that and try to build long-term relationships with sellers. The best solution to do it is to listen to sellers feedback. Sellers know best what their needs are and what are the best solutions for their businesses. The following factor determine the number of seller choosing the particular e-commerce solution. The range of notes is provided below:

1. Platform provide solutions without consulting with sellers;
2. Platform receive sellers feedback, but does not take it under consideration;
3. Platform cooperate with sellers and provide them the right solution for their needs.

The next very important factor, which was partly described in one of the previous paragraphs are the marketing processes performed by platform's owners. This factor can influence on reaching more customers as well as sellers. The range of scale is provided below:

1. Platform does not perform any marketing processes;
2. Platform perform marketing processes, but not effectively;
3. Platform perform marketing processes effectively.

Nowadays, comfort of using of particular solution is as important as a solution itself. Sellers want to have an access to their accounts in any moment from every place. It is very important to control the selling processes live and implement changes as soon as possible. This is why more and more platforms provide mobile apps, which give sellers possibility to managing their stores from anywhere in the world. The security of sellers' accounts is also an important issue. To provide safe tool for mobile phones, platforms recommend to use two-step verification for logging in to app. This solution provide comfort of managing companies processes safety. The range of notes is provided below:

1. Platform does not provide any solutions for mobile devices;
3. Platform provide safe solution for mobile devices.

Customer service for seller is very important. When sellers create their first e-commerce store or account, they do not know how to do it. Then customer service comes with help. Unfortunately, the standards of customer service are very diverse. The awareness of that issue is growing among platform's owners, but there in some cases there is a lot of work to be done. The range of scale is provided below:

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1. Platform does not provide any customer services solutions;
2. Platform provide customer service solution, but it is not well-developed;
3. Platform provide well-developed customer service solution.

A lot of platforms offer to their best seller better conditions of cooperation. Usually, partner programs are provided to the biggest seller, which generate the biggest revenue. Such programs can be a win-win strategy for both subjects of cooperation. Platform can earn more money using economy of scale and seller can generate even bigger revenue by decreasing product's individual fees. This type of cooperation do not have to be based only on the pricing policy, but can also include working on innovative solutions. The range of scale is provided below:

1. Platform does not offer any Partner Programs;
2. Platform offers Partner Programs, but only for the biggest companies;
3. Platform offers Partner Program for a wide range of sellers.

CONCLUSION

The following paper showed that:

Despite the fact, that economic factors have the highest assessment's weight, this group is not fiercely decisive. Economic issues are very important for every company, but so are functionality and reliability of platforms. Also innovations implemented by platform's owners can help reach more sellers. This is an advantage for smaller platform, which can't compete by offering lower prices to customers;

Three groups of factors, which were specified by experienced sellers shows, that the biggest platforms, which earn their money mainly on the economy of scale, have to work on other groups too. They need to provide more innovative solutions, in response to the sellers needs. It is the only way for them to build long-term relationship with existing seller and to reach a new once;

Entrepeneur who are looking for the best e-commerce solution for their business should take under consideration wide range of factors. Nowadays, there are a lot of smaller e-commerce solutions on the market, which can compete with giant e-commerce corporations.

ACKNOWLEDGMENT

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Chapter 25
Security Framework for Supply-Chain Management

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ABSTRACT

In recent times, cyber-attacks have been a significant problem in any organization. It can damage the brand name if confidential data is compromised. A robust cybersecurity framework should be an essential aspect of any organization. This chapter talks about the security framework for cyber threats in supply chain management and discusses in detail the implementation of a secure environment through various controls. Today, a systematic method is used for handling sensitive information in an organization. It includes processes, people, and IT systems by implementing a risk management method. Distinct controls dedicated to different levels of domains, namely human resources, access control, asset management, cryptography, physical security, operations security, supplier relations, acquisition, incident management, and security governance are provided. Companies, contractors, and any others who are part of the supply chain organization must follow this security framework to defend from any cyber-attacks.

BACKGROUND

Cybersecurity threats pose a significant risk to any organization. According to 2018 average time to detect a breach takes up to 197 days (Ponemon, 2018) This can impact business, brand name, reputation, and revenue. To address this issue in supply chain-based organization and to enhance the cybersecurity, a security framework implementation is developed. A supply chain is a system of organizations, people, activities, information, and resources involved in moving a product or service from supplier to customer (Wikipedia, 2019a). The framework focuses on process, business drivers, people, and IT systems management by implementing a risk management approach.

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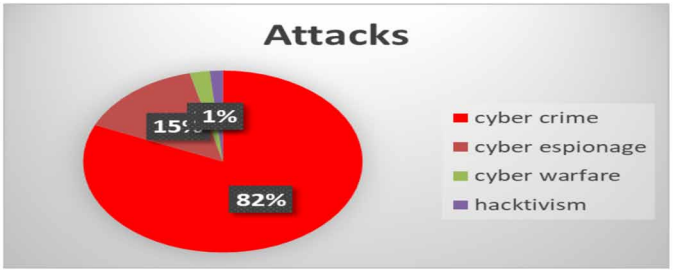
Figure 1. Attack coverage
Source: (Passeri, 2018)



Setting the Stage

Cybercriminals infiltrate into an organization to steal sensitive information. Cyber breach is the worst nightmare in the Information Technology world. A few impacts are damage to the brand name, litigation, financial losses, and data theft (Ponemon, 2018). As of 2016 cyber-attack have caused loss of around $ 450 billion to the international economy and it's on the rise every year. The primary motivation in attack scenario as shown in Figure 1. Cybercrime-related attacks top the charts when it comes to the different motivation behind the attacks (Appendix 1).

SOLUTION APPROaCH

In recent days, the cyber-attacks towards supply chain management (SCM) have been very successful. Attackers target a weak or less secure member in a supply chain to gain access to the organization. Some of the weaker networks are mentioned below in Figure 2. one of the main reasons for the successful attack is no awareness about security in the organization and its vendors and everyone in the supply chain. Attackers use this to phish emails of the employees and send malware to infect the machines and infiltrate into the network to steal sensitive information. Attackers can request ransoms by encrypting essential data for an exchange of decryption key.

To fix these cyber risks, a security framework is required. A pure knowledge of security concerns, business processes distinct from the use of technology is needed. Every organization has its unique methods and tools to achieve the results reported by its framework. However, in this paper, This Paper propose one single security framework that must be followed by the organization and the companies in its supply chain. As described in Figure 3, The framework will follow five continuous and concurrent function or can be called a cybersecurity life cycle (Identity, Protect, Detect, Respond, Recover) (NIST, 2019). This process is used to identify, assess and manage cybersecurity risk in the environment proactively.

Identify

Organizations must develop knowledge of their environment to manage cybersecurity risk to systems, data, assets, and capabilities. To adhere to this function, it is necessary to have complete clarity towards

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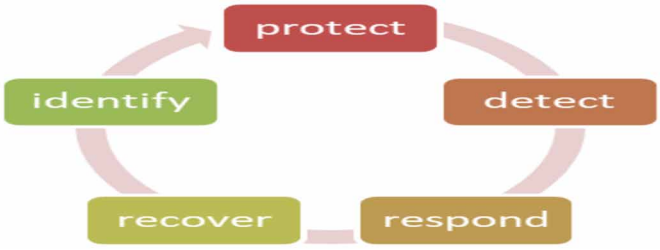
Figure 2. Weak networks in SPM

Figure 3. Cyber security life cycle



physical and digital assets and their defined roles, responsibilities and its interconnections. Understanding the risk factors are necessary to create policy and procedures to control the risks.

Protect

This function must be used to develop and implement relevant protection and defense during or to prevent a cybersecurity event. To adhere to this, the organization should control physical and digital asset access and provide adequate awareness session to the employees. The process is to maintain baseline settings of network operations, secure sensitive information and suitably repair the incident and deploy necessary security technologies to protect the organization.

Detect

During a security breach in the organization must have relevant controls for identifying security detections or events. This function promotes the use of continuous monitoring tools such as (Security Incident Events Management) SIEM, (Intrusion Detection System) IDS to detect any anomaly detections in the network. Policies must be created in the framework on the usage of these monitoring systems to prevent security incidents in the organizations.

Respond

If a security incident happens, the organization must possess the capability to hold the impact. To adhere, this function must be used to create a successful security response mitigation plan and perform all

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necessary steps to fix the incident at priority. The response plans must be documented and tested at a specified interval to check its capability.

Recover

This function must be used to develop a business recovery plan to restore services that were damaged due to a security incident. The recovery plan must be active to perform the business restoration and document the learned lesson in the updated business strategy record. Prioritizing the recovery activity is an essential factor when it comes to timely recovery of services.

TECHNOLOGY CONCERNS

To create this distinct security framework, several security guidelines, global policies, best practices that are described in several security frameworks such as ISO 27000 K, NIST, PCI DSS, COBIT, HIPAA, and SOC as shown in Figure 4 are used. This framework is built towards domain-specific security so the framework can provide a strong semantics for understanding, managing, and remediating cybersecurity risk to all stakeholders in the organization. It can help to identify and prioritize the action for overcoming cybersecurity risks, and it is an excellent tool for aligning policy, business, and technological strategies for managing that risk (International Organization for Standards, n.d.; NIST, 2019; PCI Security Council, n.d.; NIST, n.d.). Using this framework cybersecurity risks across the entire organization, companies and partners in the supply chain can be managed. The purpose of this framework is not to replace an existing framework; preferably it can be used to overlay into the current process of the organization to find the security gaps.

Companies from around the world have embraced the use of the NIST Framework, including Amazon a leader in online supply chain management process, JP Morgan Chase, Microsoft, Boeing, Intel, Bank of England, Nippon Telegraph and Telephone Corporation, and the Ontario Energy Board (PCI Security Standards Council, n.d.; NIST, n.d.). ISO 27K is the internationally recognized standard that stipulates the requirements for an ISMS (information security management system). As of 2017, there are around 39000 companies that are ISO 27k certified (International Organization of Standardization, 2018) Any

Figure 4. Cybersecurity framework

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company that handles client credit cards or payment card data must accomplice with the mandated PCI DSS framework to be protected from any data breach. Any company that handles customer healthcare and customer healthcare insurance related industries should follow accomplice HIPAA to be protected from fraud and theft. Control Objectives for Information and Related Technology (COBIT) is a framework developed in the mid-90s by ISACA, an autonomous organization of IT governance experts. This framework started primarily with concentrating on overcoming technical risks in organizations and has now evolved recently with COBIT 5 to introduce the alignment of IT with business-strategic intentions. It is the most commonly adopted framework to obtain compliance with Sarbanes-Oxley rules (SOX).

TECHNOLOGY COMPONENTS AND FRAMEWORK IMPLEMENTATION

As mentioned earlier this framework will have a domain-specific control-based design for implementation of the security. The domains taking part in the security framework are Human resource, Asset Management, Access management, Cryptography, physical Security, Communication and operations security, Supplier relationships, systems acquisition and Maintenance, Information security and Incident management, Compliance and governance as mentioned in Figure 5. This framework will provide cybersecurity requirements in each domain to find gaps in the supply chain management organization. This framework must be followed by all the companies, vendors, consultants that belong to the supply chain. This method will help find the necessary business service where security needs to be prioritized.

HUMAN RESOURCE SECURITY

The primary objective of human resource security is to ensure that proper background verification is done and audited at several intervals. The various reasons why it's necessary are listed below:

- Disclosure of criminal convictions.
- To identify if the employee has a history of alcohol/drug abuse.
- Improved quality of the applicants.
- Reduce incidents and losses to the organization.

The background verification mainly checks for the employee's address, identity, education, previous employment, drug screening, and criminal checks.

Figure 5. Security domains

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The pre-employment screening is done by agencies that must be FCRA (Fair Credit Reporting Act) compliant. This act is designed to protect individuals by promoting the accuracy and fairness of information in the files of Consumer Reporting Agencies (CRA). A CRA is any company that gathers and provides information about individuals to creditors, employers, and landlords. Companies that perform pre-employment screening are also governed by the FCRA, as are the employers that utilize CRA's background services (Wikipedia, 2019b).

Five important steps of FRCA

- Purpose: Purpose of BGC must be notified.
- Disclosure: In a written document, the employee must be informed about the BGC condition.
- Authorization: Before BGC initiation written consent must be obtained from the employee.
- Certification: Summary of consumer rights.
- Adverse action: Proper adverse action must be taken during the contrary employment decision

To guarantee that employees, contractors and third-party users exit the organization, or change responsibilities within the organization, in an orderly manner. Responsibilities for implementing the change in employment or employment termination should be precisely determined and specified. The organization must achieve and support a system or set of procedures to efficiently handle the quitting of employees or the withdrawal of designated duties for employees and contractors including other third-party users. A method must also be included for the removal of assigned contracts resulting from a change in employment status for employees, contractors and other third-parties. The organization should guarantee that valuable operational skills or knowledge have been transferred to other resources before the separation of the employee or contractor (Biswas, 2013). The control framework listed in Table 1 must be implemented throughout the supply chain to avoid any breach related to Human Resources.

Framework Control

Some most commonly used software in Human resource domains are solutions provided by ADP.

Access Control Security

Access control is a system or mechanism that controls access through the authorization or revocation of rights to logical or physical assets within an organization. The objective is to regulate who can view what and how a resource s utilized in an organization. There are two types of security:

- Physical access: which controls access to buildings, campuses, (Offshore Dedicated Centre) ODC's, IT assets.
- Logical access: which control access to computer systems, data and system files.

The primary process of the access control is to provide identity authentication and authorization of employees with the use of passwords, security tokens, biometrics. Organizations also use multifactor authentication for a layered defense. The main reason is to avoid the risk associated with unauthorized access into an organization. It is one of the fundamental elements of a security program. Organizations must have procedures that must define access to computer systems, networks, files, and sensitive data

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Table 1. Security control framework for human resources

S.NO	Control Requirement	Evidences Required for Control Requirement
1	Supplier Chain Management Company background checks as per Background check policy shall be completed for every employee working in the company, vendors, consultants and all contractors	HR confirmation on completion of the Background check for employees and associates
2	All the employees in the company, vendors, consultants and all contractors must be screened as per the client mandatory Background check (example: Criminal Background Verification, reference checks, drug screening etc.) before commencing the employment.	The client required Background checks completion report for all employees and associates working in company, vendors, consultants and all contractors
3	All the employees (company, vendors, consultants and all contractors) working for the client must be required to adhere to the client specific non - disclosure/ confidentiality agreement.	1. List of all the associates working for the client (company, vendors, consultants and all contractors). 2. Electronic Copies of the client (Non-Disclosure Agreement) NDA's signed by associates (company, vendors, consultants and all contractors) working for the client.
4	All employees (company, vendors, consultants and all contractors) shall complete all client mandated security awareness training as agreed with the client	Training trackers and completion records of all employees (company, vendors, consultants and all contractors)
5	Employees (company, vendors, consultants and all contractors) moving or quitting shall return all assets that belong to the company including a). confidential documents stored on portable storage media or in paper formats. (eg: process documents, Technical procedure documents etc.) b). all electronic equipment (eg: laptops, tablets mobiles)	1. Off boarding process documents. 2. Latest off Boarding account tracker. 3. acknowledgements of assets returned/ return receipts returned by the employee.
6	Employees shall not share user passwords among themselves.	Number of past (last six months) security incidents involving password sharing
7	The employee shall adhere to acceptable usage of client resources (email, internet and client provided storage etc.)	Some past (last six months) security incident involving misuse of client provided resources.
8	The employee shall not share company or client confidential data with unauthorized individuals working within or outside the company	Some past (last six months) security incidents involving unauthorized information sharing of company or client confidential data.

(International Organization for Standardization, n.d.; PCI Security Standards Council, n.d.). Access management, or identity management, can also be thought of as Access control. Access control discusses elements to manage access to information assets and facilities. The controls are concentrated on the protection against accidental loss or damage, threats, overheating etc. It requires documented control policies and procedures, removal, registration and review of user access rights, including physical access, network access and the control of privileged restriction of access to program source code.

Few vital values to have in mind when designing access controls are:

- Ensure controlled access to services based on rights and privileges allotted to the specified user.
- Employees have the right level of access to execute their jobs effectively and no more beyond that point.
- Perspectives and views ensure that third party viewers and clients cannot view or modify implicit and critical memory locations.

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- The system must allow for and aid audits and the tracing the exploitation of services.
- The system must also provide an intuitive and hierarchical interface to change the rights of users whenever required
- It must adhere to and fortify the regulatory requirements of the organization.

The control framework listed in Table 2 must be implemented throughout the supply chain to avoid any breach related to Access control.

Framework Control

Some famous software in the market for identity access management are from IBM, one login etc.

Asset Management Security

The assets are nothing but any hardware or software that is owned by the organization. An asset is described as "Any item of commercial value owned by a corporation.". There must be a basic understanding of asset types and their business context. The organization should identify such interdependencies and obtain a relevant plan for the indirect "enablers" that are needed to optimize the use of physical assets. also, organizations that are profoundly dependent upon physical assets should similarly understand that losses in the management of other asset types may have an intense result on the overall performance of their organizational, physical assets and their performance. Organizations should acknowledge that every asset will need to be managed in a holistic and regulated manner.

- Human assets: the knowledge, behaviour and competence of the workforce hold a significant impact on the performance of every physical asset.
- Financial assets: financial resources are needed for infrastructure expenses, development, support and materials
- Information assets: quality data and information are essential to produce, optimize and execute an asset management plan.
- Intangible assets: the organization's status and vision can have a notable influence on operating strategies, infrastructure investment, and associated costs.

An organization should be in a place within the company to recognize the physical, information based or environmental assets it owns, and be able to maintain and defend them properly. Significant factors to acknowledge when developing an asset data management approach include:

- Inventory (information on what assets you own & where they are)
- Ownership/responsibility (Information on who is accountable for each asset)
- Importance (Information on how significant every asset is in relative to other assets)
- Organize acceptable-use practices for information and assets.
- Establish regulatory systems for the labelling of information about any asset and its dependant assets.
- Organize the return of asset procedures (policy or plan for employee exit procedure?)
- Protection for Assets (is each asset appropriately protected?)

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Table 2. Security control framework for access control

S.NO	Control Requirement	Evidences Required for Control Requirement
1	Every employee in the organization shall be given a unique ID and password to access systems.	1.List of all associate in the organization 2. List of all associates with access to the client organization.
2	A process for terminating the access privileges of associates on the client systems shall be established to ensure: a) Authentication details and access privileges are revoked promptly on all systems to which the user has access. b) Login credentials (User ID, digital certificate, or user name) are deactivated. c) Access profiles/accounts deleted.	1.Up to date process document for access deprovisioning. 2. Up to date movers and leavers. 3. Client acknowledgements (email proof).
3	The policy of separation responsibilities shall be observed while requesting access to the client organization. (e.g. developers must not have access to production network)	1. Logical Access request, process documents, sample forms and email to the client. 2. Current associate logical access list with assigned roles details. 3. Segregation of Duties (SOD) Matrix.
4	Client allocated ID's shall not be used by scripts or automatically invoked programs. A separate ID with no interactive login permissions shall be used for any such purposes. Whenever such ID's shall be used, this shall be documented, and a client approval sought.	1. List of accounts that are being used by scripts or automatically invoked programs (e.g. Batch jobs) and evidenced that associates are not using them for logging. 2. Email approval obtained from the client for the use of any ID's by script or automatically invoked programs.
5	All the systems including servers owned by the organization must be administered by system admins and should be a complaint to organization security policies w.r.t. Antivirus, unique user ID administration through Microsoft Active Directory, patch management and Operating system hardening.	1. Inventory of all the machines in the organization and its vendors. 2. The evidence is demonstrating system compliance to organizations information security policy.
6	Additional controls shall be applied to special access privileges on the organization, and its vendor's systems include(e.g., "root" in UNIX, "Administrator" in windows etc.): a) define the scope of special access privileges. b) restricting the use of special access privileges to narrowly defined circumstances. c) require a manager or higher approval for the use of special access privileges.	1. List of all special access privilege accounts. 2. Manager approval emails. 3. Privileged access review/ reconciliation reports.
7	All employee access to the folders tools etc. shall be documented and reviewed periodically as per the project configuration management plan	1. UpToDate approved configuration management plan. 2. Access review reports or organization audit results.
8	The authorized organization representative shall approve user ID creation for all associates in the chain.	1. User ID creation process document and form/emails to the client. 2. Client approval for user ID creation.
9	Shared user ID's on the organization shall not be used unless special circumstances apply. Whenever such user ID needs to be assigned this shall be documented, approval sought from an authorized representative and subject to additional controls.	1. List of all shared user ID's on client systems. 2. Process for Management of shared User ID's. 3. Client approval is obtained for the use of shared ID's.
10	Associates using tokens to authenticate to client network/ systems shall be advised to a) Keep passwords for access to tokens confidential (i.e. to avoid making them visible to others by writing them down or disclosing them to others) b) Protect tokens against loss, theft and misuse (e.g. avoid sharing with unauthorized individuals) c) Report if the token has been lost or stolen.	1. Inventory list of all the client provided tokens. 2. Notifications (e.g.: email) to client for last / stolen tokens.

Asset management is typically collecting a detail of organizations hardware and software inventory. It involves a process to secure the assets by creating a list to continuously use the captured data of the asset to minimize any risk associated. IT Asset management follows the IT asset life management cycle as shown in Figure 6. Lifecycle is a systematic process. It starts with strategic planning on what kind assets are required for the organization, how to procure them. The second step is to deploy the procured asset into the organization and perform the process to maintain it and support the asset if the case of any troubleshooting requires. After the end of life, the asset is retired or sent to disposal. Every organization has a complete process for this management life cycle. To make sure that asset management has no weak spots and to retaliate any breach, the control framework from Table 3 must be implemented.

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Framework Control

Software named Maximo from IBM is one of the most famous asset management software's in the industry. Manage engine from Zoho Corp is an emerging solution for IT asset management in the market. These software's can be used to track asset inventory, scan and register assets and maintain integrity of the system.

Cryptography Security

Cryptography is the analysis and construction of protocols that would stop any third party from viewing private communication between two respective parties. In this digital age, cryptography has developed

Figure 6. Asset management life cycle

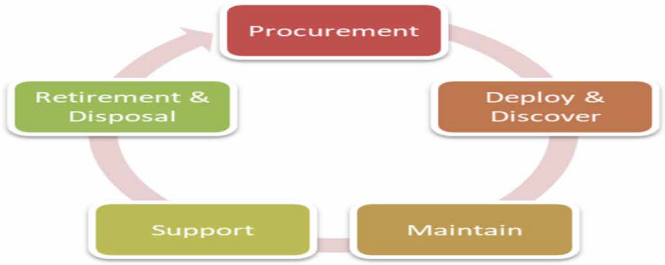

Table 3. Security control framework for asset management

S.NO	Control Requirement	Evidences Required for Control Requirement
1	All assets in the organization or all client-provided assets shall be recorded in an inventory that shall be: a) Signed off by the client or Senior Manager. b) Protected against unauthorized change. c) Kept UpToDate and copied to a secure location regularly. e) independent review has to be done.	1. The client asset inventory (Hardware and software) in the internal inventory system. 2. Periodic review evidence. (e.g., emails or system logs)
2	All assets in the organization or client provided assets shall be handled as per information security requirements contractually agreed with the client	1. Evidence that all client is classified as per company or client classification policy. 2. Access granting and authorization evidence (emails or system logs) 3. Copy of acceptable usage policies of the client. 4. Associate's acknowledgement of the client's acceptable usage policy. 5. Notification to the client on lost or damaged assets.
3	All information shall be classified as per the organization classification policy or the client classification policy as agreed with the client.	1. UpToDate approved configuration management plan with asset classification details. 2. Sample documents (e.g., project plans, design documents etc.) with the classification label evident.
4	Upon contract termination, asset reallocation or decommissioning all client data shall be returned or securely destroyed	1. System-generated requests raised. 2. Asset disposal tracker/register. 3. Secure disposal logs (e.g., disk wipe reports/ logs) 4. client email confirmation on return of client data.

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to address the encryption and decryption of any private communications over the internet and computers, a branch of network and cybersecurity, in a way far more complicated than anything the world of cryptography had observed ere the appearance of computers. Cryptographic algorithms must satisfy four main factors:

- **Confidentiality**: Protection of data from unauthorized subjects.
- **Integrity**: Preventing any unauthorized subjects from modifying the data and preventing authorized subjects from making any unauthorized modification.
- **Non-Repudiation**: This function guarantees that the subject of any event or activity can't deny that the incident ever occurred.
- **Authentication**: This function verifies that the claimed identity is valid authentication.

Cryptographic cybersecurity aims to make sure the encryption system follows all the above four criteria because the strength of encryption not only depends on computer programs but also human behavior. Some well-known encryption algorithms are AES, DES, RSA. Encryption is often a computationally intense process and may deteriorate the performance of infrastructure if not achieved optimally. Be sure to determine the administration requirements of end users and enterprise services before implementing any encryption mechanism. One must develop an implementation strategy, complete test plans, gather requirements and deploy the following best practices of products, and efficiently maintain ongoing encryption solutions. This security control framework in Table 4 will help to implement the cryptographic function and where to implement it around the organization and its supply chain to maintain encryption related security.

Framework Control

Several companies such as Microsoft, Symantec and McAfee have their own software for the purpose of full disk encryption.

Table 4. Security control framework for cryptography

S.NO	Control Requirement	Evidences Required for Control Requirement
1	Cryptography shall be used to a) Protect the confidentiality of sensitive information at rest and in transit (e.g., VPN, Email encryption etc.) that is subjected to contractual, legal and regulatory related encryption requirements (e.g., Payment card industry security standard (PCI DSS), US Health Insurance Portability and Accountability Act (HIPAA)). b) Encrypt all data residing on associates system.	1. Evidence that the sensitive data is encrypted at rest and in transit (e.g., VPN to connect to client network) 2. Evidence that all company laptops used in the account have data encryption software installed (e.g., bit locker software, Full disk encryption software's)
2	The strength of encryption (encryption algorithm, Key length) used to encrypt data at rest and in transit shall be as per organization or client mandated standards.	The encryption algorithm and key length details (e.g., AES 128/256, 3 DES 168 Bit)

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Physical Environment Security

The term physical security relates to actions taken to protect buildings, systems, and associated infrastructure upon threats linked with their physical environment. Physical safeguards are usually ignored but are very critical in protecting data. Physical security, over the decades, has grown sequentially more challenging for organizations. Technology environments presently provide more requirements for contingencies due to increase in the vulnerabilities. USB drives, tablets, laptops and smartphones allow for information to be stolen or lost because of their probability. Physical security is the protection of software, hardware, personnel, data and networks from physical events and actions that could cause severe damage to an organization and its supply chain. It includes protection from the flood, fire, natural disasters, theft, burglary, terrorism and vandalism. Physical security is often neglected, and its importance is underestimated in favor of more technical threats such as hacking, malware, and cyber espionage. Despite, breaches of physical security can be carried by brute force and little or no technical expertise on the role of an attacker. Several controls such as surveillance, security guards, biometric, turnstiles, access controls, walls, fences are part of security hardening. Physical security steps should be adequate to deal with foreseeable threats and should be examined regularly for their functionality and effectiveness.

Physical security controls and preserves sources in the form of technical, administrative and physical controls. Access control systems, auditing systems and intrusion detection systems are examples of some technical controls. Few examples of administrative controls are facility design, site location, building construction, employee controls and emergency response. Physical control examples include the varieties of building materials utilized and securing perimeters including locks, fencing and guards.

Deterrence, detection then delay, denial are some controls used for defending the environment. Efforts to secure physical resources should be prevented using gates, fences and guards around the organization. Vaults and locked doors guarding physical assets through denial. Physical Intrusion detection systems (IDS) and alarms are the subsequent lines of protection and caution first responders if a violation is

Table 5. Security control framework for physical environment

S.NO	Control Requirement	Evidences Required for Control Requirement
1	Physical access to facilities that support or enable client infrastructure shall be protected against unauthorized access as agreed with the client	1. List of current associates in the organization and at vendor end and list of user ID's enabled on the access control system. 2. Evidence of periodic physical access reviews conducted by the account (e.g., emails, system logs etc.) and discrepancies (if any) corrected. 3. Physical access entry exits logs as per retention period agreed with the client.
2	All physical and environmental security requirements as agreed in the contract with the client shall be implemented.	Depending upon the applicability: 1. CCTV camera retention logs as per client agreed retention period. 2. Logs for the materials that come Inside and goes outside the facility. 3. Mobile phone, paper or handbag submission at the entry of the organization. 4. Delay door alarm activation status. 5. dedicated security guard's deployment around the premises. 6. Visitor entry and exit logs with approvals as per client agreed retention periods. 7. Fireproof safe for storage of physical backup tapes.

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discovered. If attackers approach their target, security measures such as a remote lock on a computer must delay the suspect from obtaining assets until police or guards arrive.

It is not enough for controls to be present to manage the physical environment, there must also be a constantly evolving strategy put in place that utilizes these controls. The organization needs to build a team that is accountable for planning and designing a physical security program. The security team should continuously develop the program using the defense in depth approach. This security framework in Table 5 provides strong control check over the above implementations so that any breach related physical security can be mitigated.

Framework Control

There are several companies that exist to provide physical security solutions for its various aspects, like Aventura Turnstiles which provides access control, (NEC, Telpo, Cognitec) which provides biometric verification implementations, and SECURITAS which provides security personnel as a subscription/ contract-based service.

Communication and Operations Security

Communications Security' emphasizes the security of the network and its services through controls such as network service level agreements, segregation of networks and other network security controls which are suitable to the organization. Simultaneously it also guides in safeguarding the information in transit through controls such as policies, procedures and controls for transfer of information and agreements to ensure secure transfer of information between two entities involved in the organization (Kapersky, 2017). The scope and complexity of security operations will differ among organizations based on resource levels and risk tolerance. Still, each of its' critical areas must be addressed in some manner to help relieve familiar omnipresent risks. The most critical phase of operations security is that the operations themselves need to be reliable, repeatable and performed consistently. below are some controls that are constructed by reviewing assess the confidentiality, integrity, and availability of the operations.

- **Operational Plans and Responsibilities**: Examine documentation and assess administration regarding capacity management, change management and separation of development, testing and the production environments.
- **Malware Detection and Prevention Controls**: Examine their level of effectiveness in the organization.
- **Data Backup Plan**: Decide whether backup methods and procedures are sufficient for both off and on backup management.
- **Logging and Auditing**: Evaluate whether they are implemented efficiently so that security evaluations can be conducted to detect unauthorized access, record user activities and tampering.
- **Installation of Operational Software**: Assure the organization meets licensing conditions.
- **Implementation**: A regular vulnerability management program to be implemented to test infrastructure for known vulnerabilities that can be exploited and assure that there is an active process in place to control and manage remedial actions.
- Setup a pipeline to prepare organizations for audits to reduce risk of interruptions.

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Operations security helps the organization to place appropriate controls to ensure everyday activity is carried out in a secure and controlled manner. It includes ensuring changes to information assets are carried out efficiently, documenting operating procedures the information assets are protected from malware, and vulnerabilities & other threats, controls to assure the backup is executed efficiently to assure timely availability of information, l monitoring and logging of employee actions and guaranteeing continuous development through Information security systems audit & mitigations. In a nutshell, this security framework in Table 6 will help the organization and its partners in the supply chain to place the security controls which are specific to Operations security and communication network security and to protect the information which is in transit.

Framework Control

Examples of various companies/software that provide protection from the issues are as follows:

- Malware detection and removal - Symantec, McAfee
- Encryption of data transferred over the network - Sophos, Cisco, Juniper
- Backup - Veritas, McAfee
- Security Incident and Events Management - IBM QRadar, Manage Engine Event log analyzer.
- Vulnerability Detection and Management: GFI Events manager, Nessus, Netsparker
- Data loss Prevention - Symantec, McAfee, Sophos

Supplier Relations Security

Supplier relationship management (SRM) is the system of strategically planning and managing of all interactions with third-party organizations that supply goods and services to an organization. In use, SRM involves creating closer, more sustainable relationships with essential suppliers to realize and uncover the original value and decrease the chance of failure.

Supplier relationship management is the enterprise-wide well-organized assessment of suppliers' capabilities and assets concerning overall business determination, the strategy of what actions to involve in with different suppliers, and execution and planning of all communications with suppliers, systematically across the relationship life cycle. The SRM focus to develop a two-way mutual beneficial relationship with its partners to deliver a significant level of innovation that could be gained by acting independently or through purchasing transaction agreement.

Since multiple parties are involved risk involved is also higher in this domain. The control framework mentioned in Table 7 must be implemented throughout the supply chain to avoid any breach related to supplier relationships.

Framework Control

System Acquisition, Development, and Maintenance

Mergers and acquisitions have become very common in organizations. The security framework ensures that information security is implemented to software systems within an organization and that security is

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Table 6. Security control framework for communication and operations

S.NO	Control Requirement	Evidences Required for Control Requirement
1	Malware protection software and up to date OS patches shall be installed on the systems that are exposed to malware including a) Servers b) Computer devices (e.g., desktops, laptops and mobile devices)	1.Latest Antivirus software and signature compliance reports for the workstations and servers used in the account. 2. Latest patch compliance reports for the workstations and servers used in the account.
2	Client mandated hardening standards shall be implemented and monitored for continued compliance	1. Copy of the client provided hardening standard. 2. Evidence of hardening validation review on systems, devices and servers
3	Organization hardening standards shall be implemented and monitored for continued compliance.	Evidence of last system compliance validation review on systems, devices and servers
4	Adequate and appropriate network level segregation (via VLANs, Firewalls etc.) shall be in place as agreed with the client	1. Up to date network diagrams. 2. Firewall rule base. 3. Details on switch ACLs.
5	All data backup on physical media shall be secured as per company or client agreed policies	1. Backup tape movement and review logs. 2. Evidence that fireproof safe is in place for tape storage.
6	Before the network (e.g., firewall) and system changes being applied to the company environment: a) Change requests shall be documented. B) Changes shall be approved by an approving authority. C) The potential business impacts of changes shall be assessed. d) Changes shall be tested to ensure vulnerabilities have not been introduced.	1. List of major system and network changes done in the last six months. 2. Evidence that the change management process has been adhered to including documentation, approval, review, testing, impact analysis and roll back plan creation.
7	Data backup shall be: a) Performed using dedicated backup management software to strengthen the security of information backup. B) Recorded in a log, which includes details about data backed up, the date and time of the backup, the backup media used and its physical location.	1. Data backup and restoration schedule. 2. Latest sample backup and restoration logs. 3. Tapes movement and review logs (if applicable). 4. Fireproof safe for tape storage (if applicable). 5. Backup encryption logs.
8	System devices (CCTV, Firewalls) and servers shall synchronize their clocks to the centralized network time protocol (NTP) server.	1. The evidence is confirming that the systems are deriving their time and date settings from the NTP servers. 2. Screenshot of sample workstations, devices and servers reflecting the correct system date and time of the NTP server.
9	Security event logging shall be in place for the systems used in the organization.	Evidence that the security event logging is enabled on the systems used in the organization and its vendors. (e.g., reports, screenshots)
10	Periodic security event/ log reviews shall be performed for critical systems (e.g., manual or by SIEM solution) as contractually agreed with the client.	Periodic manual log review reports or system generated reports (SIEM reports)
11	Security event logs must be protected and retained according to the company or client mandated retention standards.	1. Evidence that security logs stored are tamper-free (i.e. no unauthorized modification or deletion is possible) 2. Oldest log as per the company or client mandated log retention policy
12	Vulnerability scanning and penetration testing of systems, equipment and network devices shall be performed to help: a) Identify known technical vulnerabilities b) Determine the extent to which they are exposed to threats. C) Prioritize the remediation of vulnerabilities.	Evidence that a vulnerability assessment and penetration testing is conducted at least annually.
13	Firewall configuration of the account shall be reviewed regularly to ensure that: a) Each firewall rule Is approved and signed off by the business organization. B) Expired or unnecessary rules are removed. C) Conflicting rules are resolved.	Evidence that a firewall rule base review is conducted at least annually.
14	Organization or client approved software shall only be installed on systems used by the account.	1. List of client approved software. 2. Microsoft SCCM reports for the software installed on the account workstations and servers.
15	Associates shall maintain client systems as per documented and approved methods of v a) Administering users(e.g., adding new business users, updating access privileges, and revoking user access privileges) b) Monitoring key security-related events (e.g., system crashes, unsuccessful login attempts of unauthorized users and unsuccessful changes to access privileges) C) Identifying potential security	1.Uptodate and approved standard operating procedures for system maintenance as agreed with the client organization. 2. Evidence is supporting compliances to the SOP's for maintaining client systems.

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Table 7. Security control framework for supplier relations

S.NO	Control Requirement	Evidences Required for Control Requirement
1	Sound information security practices shall be ensured in all supplier relationships within the account	1. List of all suppliers used by the account. 2. Client approval for usage of suppliers. 3. Security clearance by Information Security or Governance team prior onboarding the suppliers. 4. Copy of the supplier agreement with the client and company information security requirement. 5. Evidence of a periodic security review. 6. Sample copies of client mandated NDA's signed by sub-contractors.
2	All company and client mandated security requirements shall be complied with when the supplier further outsources its services to another organization.	1. Copy of the agreement signed between the supplier and the organization to which services have been outsourced containing the company and client information security requirements.

included within the policies after any acquisition or mergers. This method helps restrict errors, loss, and the misuse of organizations information. To guarantee that security is an essential element of information systems over their entire lifecycle, including those that contribute services over public networks. The framework mainly focuses on how securely the source code is developed, its review practices, security of source code production environment, how change management is carried out in the new organization, access control review and how vulnerability assessments are carried out. This framework notified in Table 8, guides the organization and its supply chain to avoid any breach related to any new system acquisitions and mergers.

Framework Control

Change management software's: INTELEX, fresh service

Information and Incident Management Security

Real-time incidents in the organization are captured, managed, recorded and analyzed. This process is called incident management. It tries to give a sound and complete view of any security issues within an organization. A security incident can be in any form such as intrusion attempt to compromise or data theft. Strict policy violations process must be in place to avoid any such attempts. The organization must have a solid response plan to tackle any security incident and must have a dedicated team to monitor the process so every incident can be recorded and fixed by the deadline. This security framework from Table 9, guides the organization and its supply chain to avoid any breach related to incident management.

Framework Control

Examples of IT Incident management software's in the market are ZOHO's manage engine, OMNIGO and ConnectWise.

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Table 8. Security control framework for system acquisition, development and maintenance

S.NO	Control Requirement	Evidences Required for Control Requirement
1	Source code development shall follow secure coding and code review practices	1. Secure coding guidelines. 2. Code review checklist. 3. Samples of the code review performed and closure of discrepancies (if applicable)
2	Organization production data shall not be used in non-production environments.	Evidence that test data is being used in client non-production environments
3	Changes to client business applications shall be: a) Performed by a formal documented in the change management process. b) Reviewed to ensure that they do not adversely affect intended functionality or compromise security controls.	1. Change management process document. 2. Sample recent changes and relevant evidence in line with the change management process.
4	The system development methodology shall require that: a) Program coding shall be reviewed by a systems development manager to ensure that system function as intended and to confirm that security weakness (e.g. those related to hardcoded passwords, SQL/ LDAP injection attacks, cross-site scripting).	1. Sample code review reports. 2. Evidence is confirming that testing is performed in a non-production environment. 3. Segregation of duties matrix (SOD)
5	The application source code used in development environments within the company network shall be protected by a) Preventing unauthorized changes to development environments. (e.g., by using access control software) b) Applying strict version control over systems development software (e.g., by using configuration management recording access in the log)	1. List of associates with access to a development environment. 2. Evidence that periodic access review is performed. 3. Reports confirming strict version control over development software. 4. Screenshot of anti-malware solution deployed within the development environment.
6	Sensitive business information used for testing or development purpose within client environment shall be protected by a) Prohibiting the use of personally identifiable information (i.e. information that can be used to identify a person) b) Using client prescribed methods.	1. Evidence that no personally identifiable information is used to test or development environments. 2. Evidence that data sanitization has been done in a test or development environment. 3. Authorization emails for data exporting in to test or development environments. 4. List of associates with access to test and development environment and evidence of periodic reconciliation of the same
7	Secure coding being developed for the client shall be tested to determine the effectiveness of security controls before delivery of the code including a) Vulnerability assessments (to identify weakness in software and security controls) b) Penetration testing (e.g., using a black box or grey box, white box testing to simulate attack)	1. Vulnerability assessment reports for the application developer. 2. Penetration test report. 3. Any other automatic or manual application security test reports.
8	Post implementation reviews shall cover fulfilment of business requirements (including information security)	Client email confirmation on the successful implementation of business and information security requirements.

Governance and Compliance Security

Governance and compliance describe the regulatory compliance standards related to the organization and its internal control and business processes. The organization and its supply chain must adhere to

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Table 9. Security control framework for incident management

S.NO	Control Requirement	Evidences Required for Control Requirement
1	There shall be a process for managing individual information security incidents which include: a) Identifying and reporting information security incidents to the company security incident management team and the client as agreed in the contract. b) Responding to information security incidents (e.g., escalation to the information security incident team)	1. Security incident response plan with details including but not limited to security incident types and severity levels, client contracts, company contacts and SLA's for incident reporting. 2. Notifications to the client and internally within the company for past security incidents. 3. Evidence that all corrective and preventive controls resulting from the security incident have been successfully implemented.

these standards (Da Veiga & Eloff, 2007). A secure framework must include communication processes, risk controls and governance methods for maintaining compliance (Biswas, 2013).

By considering the above process, a security framework is created and has to be implemented in the organization and its supply chain. For added granularity, the specifics of the process are as follows:

- Address uncertainty and hence ensure that company objectives are achieved.
- Realize regulatory compliance obligations as specified and visualize them on a global viewpoint throughout the enterprise.
- Detect, prevent and secure potential risks within the enterprise.
- Incrementally build on the design, control and access specifications, alongside the organisations control framework.
- Implement risk management both in business strategizing and everyday operations
- Comply with the appropriate regulations and standards when designing or improving infrastructure.
- Increase the signification of stakeholder decisions by improving both awareness and accountability criteria within the company.
- Put data consolidation protocols into place for easy review procedures and future prevention protocol generation.

Solidify the following of protocol implicitly in the organization by decreasing the active input required from the end-user (be it employee or client). Controls mentioned in Table 10, guides the organization to maintain strict compliance and governance in place.

Framework Control

The company LogicGate provides various solutions to prevent and manage Governance and compliance security.

CURRENT CHALLENGES FACING THE ORGANIZATION

Some of the impediments facing the implementation of security frameworks are

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Table 10. Security control framework for governance and compliance

S.NO	Control Requirement	Evidences Required for Control Requirement
1	There shall be documented standards/procedures for monitoring information security compliance for the account which shall cover: a) Identifying the additional information security compliance obligations that are derived from the client contract, legislation and regulations	1. The account handbook that identifies and documents any additional information security requirements form the client contract and any other legal and regulatory requirements. 2. The copy of the client contract/ MSA and all associated security schedules and policies. 3. Last internal audit reports and closure status of findings (if any)
2	The account shall ensure that an internal audit is conducted of the information security requirements as mandated client agreement	Last internal audit closure report

- Lack of trained staff
- Lack of budget
- Lack of integration among tools

Lack of Trained Staff: There is a tremendous shortage of highly skilled cybersecurity professionals. In a survey by Intel, 82 percent of respondents accepted to a lack of cybersecurity skills in their corporation, 71 percent of respondents citing this deficiency accounting for primary and assessable damage. There is direct damage to the company due to the shortage of cybersecurity skills.

Lack of Budget: A Kaspersky survey confirms that there is a broad world decline in the amount spent for cybersecurity from $25.5 million in 2016 to $13.7 million till 2017 (Kaspersky, 2017). No organization must compromise when it comes to cybersecurity. ROI (Return of Investment) must be calculated appropriately by the chief security officer for implementing successful cybersecurity program.

Lack of Integration Among Security Tools: Cyber Security faces many challenges, and this is one of its main issues. Organizations use many types of security software. How is it useful if the security software doesn't talk to each other since each has its' own vendors striving to achieve their individual goals? SIEM correlation cannot help much in advanced security.

To build a security program that does not possess the above stated issues, a domain-specific control-based security architecture is required

SOLUTIONS AND RECOMMENDATIONS

This Framework is not a "Canada only" framework. Stakeholders of the private sector made it clear of the origin that global alignment is necessary to evade duplication and confusion of effort or even conflicting expectations in the global enterprise ecosystem. This framework is built in reemphasizing the needs of the now multinational environment of business. The framework's strategy recognizes and implements international standards and organization security formats. This structure can be implemented in any supply chain organization in any country.

NIST, and all the other security frameworks adopted here, has been holding regular discussions with many nations and regions, making noteworthy internationalization advancement. NIST is actively involved with international standards-developing organizations to encourage the adoption of approaches consistent with the Framework (NIST, 2018; NIST, n.d.). Implementing a unified security framework

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is a tedious process in an organization and its supply chain. But this framework is created in such a way that it can be implemented over an existing security framework of the organization. Establishing this Security control involves the coordination and cooperation of the entire organization. This security framework would give much-needed confidence in mitigating risks in the organization. Confidence in fewer chances of failure would ensure non-wastage of precious economic resources. The right approach would unquestionably do the company well in the new enterprise of the global supply chain market.

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KEY TERMS AND DEFINITIONS

Acceptable Usage Policy: An acceptable use policy, acceptable usage policy or fair use policy, is a set of rules applied by the owner, creator or administrator of a network, website, or service, that restrict the ways in which the network, website or system may be used and sets guidelines as to how it should be used.

Access Control List (ACL) in Switches: It can control the traffic entering a network. Usually, ACLs reside in a firewall router or a router connecting two internal networks. When you configure ACLs, you can selectively admit or reject inbound traffic, thereby controlling access to your network or specific resources on your network.

COBIT: COBIT is a good-practice framework created by international professional association ISACA for information technology management and IT governance. COBIT provides an implementable "set of controls over information technology and organizes them around a logical framework of IT-related processes and enablers.

Full Disk Encryption: It is a technology which protects information by converting it into unreadable code that cannot be deciphered easily by unauthorized people. Disk encryption uses disk encryption software or hardware to encrypt every bit of data that goes on a disk or disk volume.

HIPAA: HIPAA (Health Insurance Portability and Accountability Act of 1996) is United States legislation that provides data privacy and security provisions for safeguarding medical information. The law has emerged into greater prominence in recent years with the proliferation of health data breaches caused by cyberattacks and ransomware attacks on health insurers and providers.

Master Service-Level Agreement: A master service agreement, or MSA, is a contract reached between parties, in which the parties agree to most of the terms that will govern future transactions or future agreements.

Network Time Protocol (NTP): The Network Time Protocol is a networking protocol for clock synchronization between computer systems over packet-switched, variable-latency data networks.

NIST: The National Institute of Standards and Technology is a physical sciences laboratory, and a non-regulatory agency of the United States Department of Commerce. Its mission is to promote innovation and industrial competitiveness.

Non-Disclosure Agreement: It is a legal contract between two parties that outlines confidential material, information, knowledge that parties wish to share with one another for certain purpose but wish to restrict access to third parties.

PCI DSS: The Payment Card Industry Data Security Standard is an information security standard for organizations that handle branded credit cards from the major card schemes. The PCI Standard is mandated by the card brands and administered by the Payment Card Industry Security Standards Council.

Penetration Testing: It is an authorized simulated cyber-attack on a computer system, performed to evaluate the security of the system.

Security Incident: A security incident is an event that may indicate that an organization's systems or data have been compromised or that measures put in place to protect them have failed. In IT, an event is anything that has significance for system hardware or software and an incident is an event that disrupts normal operations.

Security Incident Event Management (SIEM): It is software that provides real-time analysis of security alerts generated by applications and network hardware.

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Security Tokens: A security token is a physical device used to gain access to an electronically restricted resource. The token is used in addition to or in place of a password. It acts like an electronic key to access something.

Standard Operating Procedure (SOP): It is a set of step-by-step instructions compiled by an organization to help workers carry out complex routine operations. SOPs aim to achieve efficiency, quality output and uniformity of performance while reducing miscommunication and failure to comply with industry regulations.

System Centre Configuration Manager (SCCM): It is a systems management software product developed by Microsoft for managing large groups of computers running Windows NT, Windows Embedded, macOS (OS X), Linux, or UNIX.

Virtual Private Network: A virtual private network extends a private network across a public network and enables users to send and receive data across shared or public systems as if their computing devices directly connected to the private network.

Vulnerability Assessment: It is the process of identifying, quantifying, and prioritizing the vulnerabilities in a system.

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APPENDIX

Types of Hackers

Not every hacker is evil. the word, "hacker," is usually used about cybercriminals, but a hacker can be anyone, regardless of their purposes, who use their knowledge of computer to break into a system or network bypassing security measures. Hacking itself is not a criminal activity unless the hacker is jeopardizing a system without the owner's approval. Several government agencies and organizations employ hackers to help them secure their systems. Hackers are differentiated into three types:

- White hat
- Grey hat
- Black hat

Black Hat Hackers

Black hat hackers use their knowledge to steal data by bypassing all the security protocols. They create malware to gain access to the network. Their motivation is to take confidential information from the organization. They are involved in cyber espionage and ransomware attacks. They not only steal but they also try to modify and destroy data.

White Hat Hackers

White hat prefers to utilize their skills for good rather than a crime. They are also called as "ethical hackers." An organization or work pay them for them to find out security vulnerability and fix the issue. They perform the attack vectors with permission from the organization to conduct a vulnerability assessment and penetration testing.

Grey Hat Hackers

Grey Hat are neither white or black. They are a combination of both. The grey hat accesses a network or system with our owner's knowledge. If any issues are detected, they inform the problem to fix it or grant assistance for a specific fee. They are not malicious, and they don't exploit known vulnerabilities instead try to discover new. Still, this is considered illegal because the hacker did not get the consent from the owner before the attack.

Although the term hacker tends to invoke adverse inferences when associated to, it is significant to recognize that all Hackers are not equal. If white hat hackers failed to seek out vulnerabilities and threats diligently, the black hat could find it and start exploiting it for criminal activities by collecting sensitive data.

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Chapter 26
Collaboration Planning Among Supply Chain Partners Using an ANP and Game Theory-Based Approach

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ABSTRACT

In response to current economic downturn coupled with intense global competition, the concept of supply chain collaboration has emerged as a possible solution for firms aiming to gain competitive advantage through cost reduction, increased asset utilization and improving service levels. In this chapter, the authors address the problem of collaboration planning between multiple retailers and/or suppliers in a supply chain network. Three problems are considered, namely partner selection, collaboration strategy selection, and profit allocation, among the partners entering into a collaboration. Three techniques, namely cluster analysis, analytical network process (ANP), and game theory, are used for this purpose. Partner selection for collaboration is done using cluster analysis and analytical network process (ANP) while collaboration strategy selection is made through the application of game theory. The profit allocation among collaborating partners is performed using Shapley method. A numerical application is provided.

INTRODUCTION

Supply chain collaboration, as defined by Simatupang & Sridharan (2002), is an interaction between "two or more chain members working together to create a competitive advantage through sharing information, making joint decisions, and sharing benefits which result from greater profitability of satisfying

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end customer needs than acting alone." Current economic downturn, intense global competition and fast changing customer demands have made it difficult for organizations to stay competitive in the current market place. Recession scarred customers are constantly looking for better quality and innovative products at a relatively low price. In the nutshell, organizations that are capable of selling products, or services that satisfy the above-mentioned specifications will be able to dominate the market.

In response to this challenge, the concept of supply chain collaboration has emerged as a new approach to attaining competitive advantage through cost reduction, increased asset utilization, reduced inventories, and shared business risk that arises because of the coordination of actual customer demand with supplier production plans. Effective supply chain collaboration can help organizations reduce excess inventory, shorten lead times and increase sales and customer service level. Furthermore, supply chain collaboration has allowed organizations to enhance flexibility and capabilities by fostering relationships that improve skills and knowledge, facilitate easier product development, offer access to new technologies and reduce time to market.

While supply chain collaboration amongst independent firms can often provide them with competitive advantage, however, lack of awareness regarding the presence of barriers of collaboration might impede the benefits of collaboration (Ramesh et al., 2010). A number of factors such as the level of trust between collaborating partners (Delbufalo, 2012), willingness to share information (Barratt, 2004), mistrust regarding the fairness of benefit, costs and risk sharing (Cruijssen, 2012) and availability of adequate measurement systems to support the efficiency and flexibility requirements of the supply chain (Reddy, 2001a; Karahannas & Jones, 1999) can influence the level of benefits that can be realized as a result of collaboration.

The purpose of this study is to provide a framework for facilitating collaboration amongst different supply chain partners. This involves:

1. Identification of potential partners for collaboration.
2. Determining best partner(s) for collaboration among the potential partner(s)
3. Identifying strategies for collaboration among the selected partners
4. Profit allocation among the partners' post collaboration.

The rest of the chapter is organized as follows. The next section is the literature review. This is followed by the solution approach and numerical application. The final section draws the conclusion.

LITERATURE

Partner selection is the first critical step in collaboration formation. Partner selection is a procedure of identifying ideal partners that can provide the right quality products and services at the right place, at the right quantities and at the right time (Sonmez, 2006). Proper identification of potential partners is of utmost importance for achieving successful supply chain management (Lasch & Janker, 2005). Adequate identification of partner selection decreases the purchasing costs and enhances corporate competitiveness (Ghodsypour & Brien, 2001). In the partner selection process for collaboration, identification of suitable decision-making criteria for choosing the right partner is of utmost importance. The decision-making criteria to be used for partner selection will vary across a variety of industries. For example,

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in the pharmaceutical industry, the most important criteria would be health and safety considerations, followed by quality and delivery. Similarly, in the automobile industry, reliability, durability and quality would be the three most important selection factors. In the context of supply chain collaboration, the prospective partners' decision on whether to engage in collaboration with each other or not is to a large extent influenced by the partner selection criteria. Nowadays, many other factors seem to be taken into consideration (Muralidharan et al., 2002). Ramanathan et al. (2011) recommend flexibility, responsiveness and use of technology as important metrics for supply chain collaboration. In the literature review of Cheraghi et al. (2004), 86 papers linked to partner selection factors in the timeframe 1990-2001 are summarized. They drew the top 30 most important factors for supplier ranking with quality ranking first, delivery second and price third.

Retailers usually look for capable, compatible and long term oriented suppliers who can provide high-quality products at economical prices and can commit to long term relationship. On the other hand, suppliers generally look for retailers who are honest, trustworthy and possess state of the art supply chain management information systems so that information related to the point of sales can be shared freely in a transparent manner. During the process of partner selection, firms should not only consider the financial contribution to the alliance but also take into account other criteria such as top management attitude, organizational culture, technical capabilities and long-term orientation. Bhutta & Huq (2002) are of the view that partner selection process needs consideration of multiple objectives regarded as a multi-criteria decision-making problem (MCDM). In this regard, several multi-criteria approaches have been suggested for solving partner selection problems such as multi-objective programming (MOP), analytic hierarchy process (AHP), analytic network process (ANP) and vendor profile analysis (VPA) (Cheng, 2007).

Some researchers suggest screening of potential partners in case of a large number of suppliers for possible collaboration. Pre-qualification is a systematic process of ranking several suppliers under conflicting criteria. (Ravindran & Warsing, 2012). It can also be considered as a multiple-criteria problem where the buyer trades off amongst conflicting criteria, some of which might be qualitative (Holt, 1998) for the screening of potential suppliers. Boer et al. (2001) have mentioned several techniques for pre-qualification. Some of these techniques include categorical methods, cluster analysis, data envelopment analysis (DEA) case-based reasoning (CBR) systems, and multi-criteria decision-making method (MCDM). Another crucial step in the success of collaboration is determining the right type of collaboration. There are various types of supply chain collaboration. Some of the most common ones include strategic alliances, joint ventures and cooperative arrangements (Soosay et al., 2008). Strategic alliances are generally considered as a particular form of inter-firm relationships that are supposed to be of long term and in which two or more partners share resources, costs, knowledge, risks and capabilities with the aim of improving the competitive position of each partner. Join ventures is a formal agreement between two or more firms in order to create new products and services, enter new and foreign markets, or possibly both. The main purpose of cooperative arrangements is to move from purely contractual arrangements to somewhat more trusting relationships with parties. The collaboration can be full or partial for the above-mentioned strategies. Once the collaboration partner and the type of collaboration have been decided, it is very important to sustain the collaboration by a fair mechanism of cost savings or profit allocation among the involved partners. Researchers have addressed this problem using game theory in collaborative logistics scenario.

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SOLUTION APPROACH

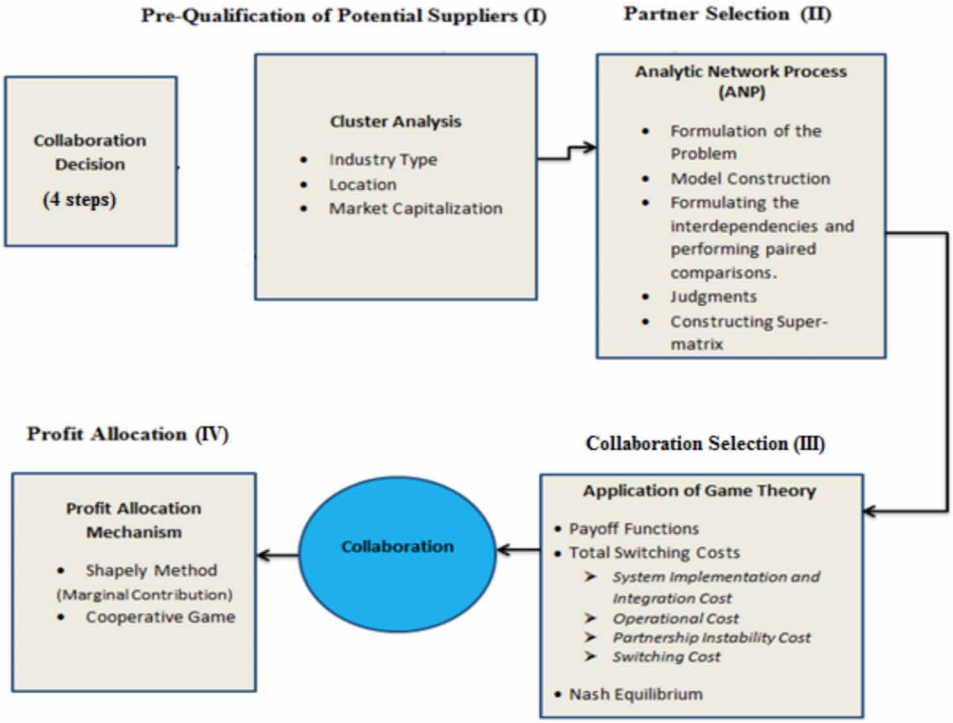
The proposed solution approach comprises four steps (Figure 1). The first step involves screening of potential partners for collaboration using cluster analysis. The second step includes an application of the Analytic Network Process (ANP) technique for partner selection. The third step involves collaboration strategy selection between retailers and suppliers using game theory. Three possible modes, i.e. full collaboration, partial collaboration, or no collaboration are discussed. The fourth and the last step involves profit allocation amongst retailers and suppliers using Shapley value.

These steps are explained in detail as follows:

Pre-Qualification of Potential Suppliers

The pre-qualification of potential suppliers is carried out using cluster analysis. Cluster analysis or clustering is the task of grouping a set of objects in such a way that objects in the same group (called cluster) are more similar (in some sense or another) to each other than to those in other groups (clusters). According to Holt (1998), the higher the likeness (homogeneity) within a group and more significant the variance between groups, the finer or more distinct the clustering. The technique is particularly useful for large high dimensional supplier databases. For instance, if a prospective retailer wants collaboration with a food and beverage company located in North America region and having a market capitalization of at least $1 million, it will be worthwhile to filter out only those prospective suppliers who fulfil these criteria. In our study, cluster analysis incorporates three factors of interest: industry type, location and

Figure 1. Steps in supply chain collaboration



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market capitalization. It is assumed that the suppliers are all ISO 9000 certified. To perform cluster analysis, NeuroXL Clusterizer software is used. NeuroXL Clusterizer uses optimized neural network technology to carry out cluster analysis quickly and efficiently.

Partner Selection

Table 1 presents the various criteria and sub-criterion used for partner selection in our study. These criteria are important for collaboration from both the perspectives of the suppliers and retailers. These include performance, compatibility, information technology systems, capability, service, risk management and long-term relationship.

To determine the weights of these criteria and partners rating for collaboration formation, ANP method is used. Since interdependence in relationships exist in the collaboration criteria (Table 1), the analytical process network (ANP) method is considered suitable. ANP method, developed by Saaty (1996), allows in resolving problems that entail both qualitative and quantitative criteria as well as take into consideration the interdependence and feedback among these criteria.

Collaboration Strategy Selection

After partner selection, the next question is to determine the type of collaboration for each partner. After shortlisting the number of partners through cluster analysis and analytical process network, it cannot be

Table 1. Partner selection factors and their criterions

Factors	Criterion
Performance	• Quality performance (e.g. ISO 9000 accreditation) • Delivery • Lead times • Development speed
Compatibility	• Cost of service • EDI capability • Strategic objectives • Management attitude • Information sharing & mutual trust
IT	• Supply chain systems • current technology (product & process) • communication systems
Capability	• Production facilities and capacity • Reciprocal arrangements • Financial position • Forecasting capabilities
Service	• Flexibility (payment, freight, price reduction, order frequency and amount • Ability to modify the product service • Technical support • After sales service (such as warranties and claims policies)
Risk management	• Willingness to share risk • Clause for arbitration and escape
Long term relationship	• Long term orientation • collaboration possibility

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assumed that prospective partners will readily agree to enter into collaboration. This is because it might not be in the best interest of a particular partner to enter into collaboration whereas it might be beneficial for the other one. In order to determine the win-win solution from the perspective of each partner, a non-cooperative game is designed where by partners make decisions independently in a manner which maximizes their own payoffs. The solution of the non-cooperative game is Nash equilibrium.

During the modelling of the game, it is assumed that collaboration, whether partial or full, will ultimately result in cost savings more than that of "no collaboration". Therefore, the decisive factor which plays an important part during the decision-making process of the partners is total switching costs. During analysis, for example, if the net benefits are high and total switching costs are low for partial collaboration for both the retailer and the supplier with respect to other types of collaboration; the dominant strategy for the partners would be to enter into partial collaboration with each other. In this case, the partners are said to be in Nash equilibrium because each one is making the best decision while taking into consideration the decisions of others.

Basic Assumptions

To investigate the collaboration mechanism, three modes of collaboration i.e. full collaboration, partial collaboration and no collaboration are proposed in the study. These modes of collaboration are developed through the combination of a wide range of supply chain contracts such as buyback contracts, quantity flexibility contracts, revenue sharing contracts, quantity discount contracts, and sales rebate contracts. The modes are developed under the assumption that collaboration, be it partial or full, will ultimately result in maximizing the total revenue of the supplier as well as that of the retailer and neither supplier nor retailer has anything to gain by changing only their own strategy unilaterally. However, the characteristics under each mode are subject to change in case supplier and retailer do not agree. In this situation, it is assumed that the retailer develops the modes of collaboration. The characteristics of each mode of collaboration are defined as follows:

Full Collaboration

In full collaboration, the partner and the retailer work like a single entity. The characteristics when both the retailer and the supplier work in full collaboration are as follows:

- The administration costs are shared equally between the supplier and the retailer.
- Inventory costs are shared equally. Retailer's warehouses and supplier's warehouses may be combined into a single warehouse or alternatively the operational costs of running the warehouses are shared equally by both the retailer and supplier.
- Transportation costs are equally shared between the supplier and retailer.
- Production costs are equally shared.
- Centralized information sharing.
- The profit from the sales of the goods is equally shared between the retailer and the supplier.
- Costs such as system implementation, operational, partnership instability and switching are shared equally between the partners.
- Joint decisions on strategic issues such as production capacities, product design, portfolio joint marketing and pricing plans.

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- Information sharing on topics such as bill of materials (BOM), orders, product descriptions, prices & promotions, product & material availability and service levels.

Partial Collaboration

In partial collaboration, limited resources are shared between the supplier and the retailer. The characteristics of partial collaboration relationship between the supplier and the retailer are as follows:

- The inventory is completely managed and owned by the supplier until the retailer sells it. This means the administration costs increase at the supplier's end.
- The supplier decides on the appropriate inventory levels of each of the products and appropriate inventory policies.
- Since inventory is completely managed by the supplier, the inventory costs are endured by the supplier alone.
- Transportation costs are fully endured by the supplier.
- Costs such as system implementation, operational, partnership instability and switching are borne separately by each partner.
- Information sharing on topics such as bill of materials (BOM), orders, product descriptions, prices & promotions, product & material availability and service levels.

No Collaboration

In no collaboration, supplier and retailer work like separate entities. There is no information sharing on topics such as bill of materials (BOM), orders, product descriptions, prices & promotions, product & material availability and service levels. Other features of no collaboration are as follows:

- The retailer decides on how much to order.
- The inventory costs are endured separately by the retailer and the supplier (Assuming both operate a warehouse and keep inventory stock).
- The administration costs are endured separately by both the supplier and the retailer.
- Production costs are endured by the supplier.
- Transportation costs endured separately by both the supplier and the retailer assuming both have a warehouse.

The costs characteristics of three different types of collaborations are summarized in Table 2.

Assumptions and Major Variables

a) The ultimate aim of the players is to maximize their profits.
b) There are three types of strategies that players can choose from: full collaboration, partial collaboration and non-collaboration.
c) In each mode, the price, unit cost and the incremental cost of the product are different.
d) The supply and demand of the products will be different under different categories.
e) Each of the two enterprises has an accurate understanding of characteristics and utility but not the action of the other enterprise before making decisions.

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Table 2. Costs characteristics of three different types of collaborations

Cost	No collaboration		Partial collaboration		Full collaboration	
	Retailer	**Supplier**	**Retailer**	**Supplier**	**Retailer**	**Supplier**
Inventory carrying cost	Paid by retailer	Paid by supplier	None	Paid by supplier	Shared	Shared
Transportation cost	None	Paid by supplier	None	Paid by supplier	Shared	Shared
Production fixed cost	None	Paid by supplier	None	Paid by supplier	Shared	Shared
Administrative cost	Paid by retailer	Paid by supplier	Paid by retailer	Paid by supplier	Shared	Shared
Fixed ordering cost	Paid by retailer	None	None	None	Shared	Shared
Expected inventory holding cost	Paid by retailer	Paid by supplier	None	Paid by supplier	Shared	Shared
System integration and implementation cost	N/A	N/A	Paid by retailer	Paid by supplier	Shared	Shared
Operational cost	N/A	N/A	Paid by retailer	Paid by supplier	Shared	Shared
Partnership instability cost	Paid by retailer	Paid by supplier	Paid by retailer	Paid by supplier	Shared	Shared
Switching cost	Paid by retailer	Paid by supplier	Paid by retailer	Paid by supplier	Shared	Shared

Game Theoretical Analysis

The solution concept of a non-cooperative game is Nash equilibrium. In the context of supply chain collaboration, a group of players such as retailers and/or suppliers are said to be in Nash Equilibrium if each one is making the best decision it can while taking into consideration the decisions of others.

In order to find the solution of a non-cooperative game, the payoff matrix of the game needs to be determined. Once the payoff matrix is determined, the next step is carrying out Nash equilibrium analysis. Before determining the payoff matrix, payoff functions need to be developed.

The notations used to derive the payoff functions and subsequent payoff matrixes are shown below.

Notations

π: payoff of the supply chain collaboration at different modes;
π_N represents the expected Payoff at “No - Collaboration Mode”;
π_P represents the expected Payoff at “Partial Collaboration Mode”;
π_F represents the expected Payoff at “Full Collaboration” mode.
I_c:I= Inventory carrying cost
T_c:T= Transportation cost
P_c:P= Production fixed cost for the supplier
A_C:A= Administration cost

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Q: Q =Quanitity of items sold
W_u: W =Unit selling price of the supplier
U_C:U= Unit production cost of the supplier
R_e:R= Expected Revenue of the supplier
P_e:P= Expected Profit of the supplier
M_c:M= Implementation cost
O_c:O= Operational cost O_c
S_c:S= Partnership opportunity cost
K_c:K= Fixed ordering cost (everytime retailer places an order)
H_c:H= Expected inventory holding cost for the retailer
Q_c = Q= Quantity of items sold
p_c= p= Selling price
c_c=c= Cost price
S_x = System implementation and integration cost
P_i = Partnership instability cost
T_w= Switching cost

$$\Delta C = \begin{cases} \Delta C_{PR} & \text{Additional costs to be incurred by the retailer in case of switching to Partial collaboration mode} \\ \Delta C_{FR} & \text{Additional costs to be incurred by the retailer in case of switching to Full collaboration mode} \\ \Delta C_{PS} & \text{Additional costs to be incurred by the supplier in case of switching to Partial collaboration mode} \\ \Delta C_{FS} & \text{Additional costs to be incurred by the supplier in case of switching to Full collaboration mode} \end{cases}$$

where

$\Delta C_{PR} = (S_{PR} + O_{PR} + P_{PR} + T_{PR})$
$\Delta C_{FR} = (S_{FR} + O_{FR} + P_{FR} + T_{FR})$
$\Delta C_{PS} = (S_{PS} + O_{PS} + P_{PS} + T_{PS})$
$\Delta C_{FS} = (S_{FS} + O_{FS} + P_{FS} + T_{FS})$

Payoff Functions (PF)

The payoff function for supplier in a non-collaboration arrangement with the retailer is given by

$$\pi_{SN}=(p_s-c_s)q_s-(I_s+T_s+A_s+P_s+H_s) \quad (1)$$

The payoff function for retailer in a non-collaboration arrangement with the supplier is given by

$$\pi_{RN} = (p_r - c_r)q_r - (K_r + H_r + A_r) \quad (2)$$

The payoff function for supplier in a partial collaboration arrangement with the retailer is given by

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Table 3. Payoff matrix

		Supplier(s)		
		Full collaboration	**Partial collaboration**	**Non-collaboration**
Retailer(s)	**Full collaboration**	π_{RF},π_{SF}	π_{RF},π_{SP}	π_{RF},π_{SN}
	Partial collaboration	π_{RP},π_{SF}	π_{RP},π_{SP}	π_{RP},π_{SN}
	Non-collaboration	π_{RN},π_{SF}	π_{RN},π_{SP}	π_{RN},π_{SN}

$$\pi_{SP} = (p_s - c_s)q_s - (I_s + T_s + A_s + P_s + H_s + \Delta C_{PS}) \quad (3)$$

The payoff function for retailer in partial collaboration arrangement with the supplier is given by

$$\pi_{RN} = (p_r - c_r)q_r - (P_r + I_r + T_r + A_r + \Delta C_{PR}) \quad (4)$$

The payoff function for supplier in a full collaboration arrangement with the retailer is given by

$$\pi_{SF} = (p_s - c_s)q_s - \{(I_s + T_s + A_s + P_s + H_s) + \Delta C_{FS}/2\} \quad (5)$$

The payoff functions *PF* for retailer in a full collaboration arrangement with the supplier is given by

$$\pi_{RF} = (p_r - c_r)q_r - \{(I_s + T_s + A_s + P_s + H_s) + \Delta C_{FR}/2\} \quad (6)$$

Payoff Matrix

The next step after determining payoff functions is to transform them into a payoff matrix as shown below in Table 3

The retailers' three possible strategies—full collaboration, partial collaboration, or no collaboration—form the rows of the matrix. Similarly, the suppliers' three possible strategies— full collaboration, partial collaboration and no collaboration —form the columns of the matrix. Each cell of the matric represents the players' payoffs under different strategies. For each outcome, row's payoff i.e. retailers' payoff is always listed first, followed by column's payoff i.e. suppliers' payoff.

For instance, the upper left hand corner above depicts that when a retailer or a group of retailers forms "full collaboration" partnership with a supplier or a group of suppliers, the retailer or the group of retailers gets a payoff of π_{RF} and the supplier or a group of suppliers gets a payoff of π_{SF}.

Nash Equilibrium Analysis

The game between retailer(s) and supplier(s) can have multiple Nash equilibriums depending on the payoff functions. By examining the possible pairs of actions, we observe that (Partial Collaboration, Full Collaboration) and (Partial Collaboration, Partial Collaboration) could be one of the Nash equilibriums under certain conditions.

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1. Partial Collaboration, Full Collaboration

The action pair (Partial Collaboration, Full Collaboration) is a Nash Equilibrium because (i) given player 2 i.e. the supplier chooses full collaboration, player 1 i.e. retailer is better off choosing partial collaboration rather than "full collaboration" or "no collaboration". The strategy (Full Collaboration, Partial Collaboration) is a pure Nash strategy which could exist when the following equations are being satisfied:

$$(S_{PS} + O_{PS} + P_{PS} + T_{PS}) > (S_{FS} + O_{FS} + P_{FS} + T_{FS}) \tag{7}$$

$$(S_{FR} + O_{FR} + P_{FR} + T_{FR}) > (S_{PR} + O_{PR} + P_{PR} + T_{PR}) \tag{8}$$

Equations (7,8) indicates that when the additional costs required for the supplier to switch to partial collaboration mode are higher than switching to full collaboration mode, the dominant strategy for the supplier would be to go for full collaboration. (i) Given player 2 goes with full collaboration, the expected additional costs of the retailer at the full collaboration mode are higher than at the partial collaboration mode. So, the dominant strategy for the retailer would be to go with partial collaboration.

Additionally, when the above equations are being met, the retailer's expected payoff is likely to be higher in partial collaboration mode than that in "full collaboration" or "no collaboration" mode. This is because in full collaboration, the administration costs, inventory costs, transportation costs and production costs are to be shared equally between the supplier and the retailer. Therefore, ΔC_R i.e total costs involved in switching to full collaboration are likely to be higher as compared to partial collaboration or no collaboration mode. In partial collaboration, all major costs like production, inventory, and transportation are to be endured by the supplier. In no collaboration, it is likely that the inventory costs and transportation costs are likely to be more than in either of the other two strategies i.e. full collaboration and partial collaboration.

(ii) given that the player 1 i.e. retailer chooses partial collaboration, player 2 i.e. supplier is better off choosing full collaboration than partial collaboration because the additional costs required for the supplier to switch to partial collaboration mode are higher than switching to full collaboration mode as depicted in Equation(7). Apart from total switching costs, all other major costs such as inventory, production, transportation and administration costs are to be endured alone by the supplier. The supplier will own the inventory until it is sold by the retailer. Therefore, there are substantial risks involved for the supplier.

2. Partial Collaboration, Partial Collaboration

The second action pair (partial collaboration, partial collaboration) is a Nash equilibrium because

(i) given player 2 i.e. the supplier chooses partial collaboration, player 1 i.e. retailer is better off choosing partial collaboration rather than "full collaboration" or "no collaboration". In partial collaboration, the below mentioned condition applies:

$$(S_{PS} + O_{PS} + P_{PS} + T_{PS}) < (S_{FS} + O_{FS} + P_{FS} + T_{FS}) \tag{9}$$

$$(S_{FR} + O_{FR} + P_{FR} + T_{FR}) < (S_{PR} + O_{PR} + P_{PR} + T_{PR}) \tag{10}$$

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They indicate that when the additional costs required for the supplier to switch to partial collaboration mode are lower than switching to full collaboration mode, the dominant strategy for the supplier would be to go for partial collaboration strategy. Given that supplier goes with partial collaboration, the expected additional costs of the retailer at the full collaboration mode are higher than at the partial collaboration mode. So, the dominant strategy for the retailer would be to also go with partial collaboration with the supplier.

(ii) Given that the player 1 i.e. retailer chooses partial collaboration, player 2 i.e. supplier is better off choosing partial collaboration than full collaboration or no collaboration strategy. This is because in partial collaboration, the additional costs of switching to partial collaboration mode are less than the costs for switching to full collaboration mode as shown in Equation 9. Moreover, in this mode, suppliers are in better position to ascertain how the retailer is going to place the orders.

Collaboration Model Development

When the partners enter into collaboration, wide range of costs is incurred. ΔC_{PR} and ΔC_{FR} represents the additional costs that will be incurred to the retailer as a result of entering into partial collaboration and full collaboration modes respectively with the supplier. Similarly, ΔC_{PS} and ΔC_{FS} represents the additional costs that will be incurred to the supplier as a result of switching into partial collaboration and full collaboration modes respectively with the retailer. These additional costs have four components:

S_{xx} represents cost of system implementation and integration costs, coordinating and integrating business process among partners, and translating and integrating data among systems.

O_{xx} represents the operational cost of running collaborative systems. This includes salaries of additional personnel to be hired specifically for running and maintaining collaborative systems and costs incurred as a result of operating those collaborative systems.

P_{xx} denotes the value of the benefits missed out by not implementing a more beneficial partnership (Gibbons, 1995). In other words, it is the cost incurred by not exploiting the advantage that would be had by adopting a more productive relationship with the partner.

T_{xx} signifies costs of switching partners. The costs are considerably high as a result of switching partners. For instance, inflexible systems such as EDI involves high costs for switching to other partners which leads to greater partnership opportunity cost.

Therefore, when partners are faced with the decision of choosing between non-cooperative and cooperative strategies, ΔC_{PR}, ΔC_{FR}, ΔC_{PS}, ΔC_{FS}, which denote the additional costs to be borne individually by each retailer and the supplier in case of switching to partial collaboration or full collaboration mode respectively, are crucial during the decision making process of collaboration. Great emphasis is placed by the partners on these costs when deciding about entering into partnership with each other or not. In case the additional costs to be entailed in cooperative relationships are higher than that of non-cooperative relationship, the firm's preferred choice would be to opt for no collaboration strategy.

In collaborative supply chain management, low switching costs are preferable for most situations. Therefore, our decisions regarding collaboration mode are based on low switching costs. The costs S_{xx}, O_{xx}, P_{xx}, T_{xx} are compared from the perspective of each partner, and the final decision regarding which type of collaboration will best suit an individual partner is based on that comparison. Other costs such inventory carrying costs, transportation costs and production fixed costs etc. are important too but not

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the main focus during the decision making process. However, after entering into collaboration, partners can stress each other to restructure the supply chain processes and operation systems so that reductions can be made in the inventory carrying costs and other related costs since the costs in partial or full collaboration are to be shared equally by the partners.

Profit Allocation Mechanism Using Shapely Method

The last step in the process is developing a profit allocation mechanism via Shapley method. Profit allocation amongst the prospective partners is designed as a cooperative game since a coalition between a supplier and the retailer has already been formed and each has its own payoff function. Shapely value is a solution model in cooperative game theory. Assuming that a coalition of players collaborates, and attains a specific overall gain from that collaboration; as some players might contribute more to the alliance than others or may have different bargaining power, Shapley value allocates profit according to the "adding value" each partner brings for the alliance. This ensures that partners are rewarding corresponding to their contribution in the coalition (Ferguson, 1998).

The Shapely value is given by:

$= (\ldots\ldots\ldots,)$, where for $i=1,\ldots.n$, (11)

The summation as shown in the formula above is basically the summation over all coalitions s that include i. $[v(s)\text{-}v(s\text{-}\{i\})]$ is an amount by which the value of coalition $s - \{i\}$ rises whenever player i joins the coalition game. Therefore, in order to determine, $\Phi_i(v)$, we need to list all coalitions that contain I, determine the value of player I's contribution to that coalition, multiply this by $(|s| - 1)!\,(n - |s|)!/n!$ and finally, derive the sum. (Ferguson, 1998).

In our study, it is assumed that in partial collaboration, each partner has complete control over pricing decisions. For instance, the payoff payoff function for retailer in partial collaboration arrangement with the supplier is represented by

$$\pi_{RP} = (p_r - c_r)q_r - (I_r + T_r + A_r + \Delta C_{PR}) \quad (12)$$

In the equation, p_r, c_r, q_r represents the retaile price, wholeslae price and the number of items sold to the end customers respectively by the retailer. In partial collaboration, the retailer is free to set pricing on its own. However, suppliers expect retailers to set resonable prices since suppliers are bound to re-buy the unsold inventory from the retailer. Usually, a supplier sets a limit for re-buying the unsold inventory. Therefore, it is in the best interest of the parties to charge a resonable price from the end customers. Inventory costs, transportation costs and adminsitrative costs are shared between the retailer and the supplier. However,total switching costs are endured separately by the partners in partial collabration.

Similarly, the payoff function for supplier in partial collaboration arrangement with the retailer is represented by

$$\pi_{SP} = (p_s - c_s)q_s - (I_s + T_s + A_s + P_s + H_s + \Delta C_{PS}) \quad (13)$$

p_s, c_s, q_s denotes the retaile price, cost price and the total number of items sold to the retailer respectively.

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In partial collaboration, the supplier is also free to make pricing decisions on its own. However, in the case of full collaboration, the partners work as a single entity. The pricing decisions are made individually by each partner like in partial collaboration. However, the total switching costs are shared equally among the partners. In full collaboration, there is a possibility of retailer paying more total switching costs than the supplier or vice versa. This is the essence of full collaboration. Full collaboration promotes the culture of trust and commitment. Retailer normally gets heavily discounted prices from the supplier. As a result, the retailer will be in a better position to sell the goods at a reduced price to end customers, which in turn, would increase demand from the customers and ultimately give both retailer and the supplier a completive edge from their rivals as a result of selling more goods at an affordable price. This is the main reason why most retailers and supplier enter into collaboration. In full collaboration supplier is able to reduce its operating costs as a result of better forecasts, reduced demand variability and better information for sales & operations planning (S&OP).

When calculating the final payoff functions for the partners, Shapely value is interpreted in terms of expected marginal contribution. Marginal contribution can easily be determined by taking into account all the possible orders of the players entering the coalition. The amount a player receives through this method is dependent on the order in which the players join the coalition. Shapley value is an average payoff to the players provided players are entered in entirely random order (Ferguson, 1998). Shapely Value method ensures that partners who contribute more to the coalition should be paid more and vice versa.

Numerical Application

Taylor Sons (hypothetical organization) has decided to open its new outlet in Montreal. Taylor Sons is one of the Quebec's largest regional retailers in the food and beverage industry. It is an expensive brand with revenues exceeding $500 million. Some of Taylor's products include dairy products, confectionery, bottled water baby food, pet foods, coffee, breakfast cereals, and ice cream. The Chief Manager of the new outlet has been given the task to search for new appropriate suppliers who can offer quality goods at an affordable price. Supplier selection is a daunting task for any firm, and it requires intense planning to develop a framework which ensures prospective suppliers will be able to conform to their particular set of requirements.

The Chief Manager is aware of other retailers' market positions. His vision for this new outlet is to increase its competitiveness against both local and foreign competitors operating in the food and beverage industry in Montreal. The Chief Manager believes that the best way forward in accomplishing this goal is to move beyond "arms-length" relationships with its prospective suppliers to "long-term collaborative" ones. He is fully aware of the advantages which will be realized as a result of going into collaboration with its prospective suppliers. There are numbers of local and foreign suppliers available in Montreal region who can cater to the needs of the Taylor Sons. During research by the Chief Manager, 72% of Montreal's region suppliers were willing to enter into collaboration while 28% rejected the idea.

Proposed Approach

Taylor Sons is provided with a list of 1233 potential suppliers. The list contains important information about the potential suppliers such as region, country, market capitalization and industry type. For prequalification, Taylor Sons considers only three factors: industry type, market capitalization and location.

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Table 4. Data set of potential suppliers

No.	Name of Company	Industry Type	Market cap. (Year end, Millions. USD)	Country
1	JBS S.A	1.30	68840.00	5.00
2	A123 Systems, Inc.	1.80	17.00	1.00
3	Aaron's, Inc.	1.60	2290.00	2.00
4	Nestle	1.30	51861.00	5.00
5	Pepsico	1.30	59749.00	5.00
6	Unilever	1.30	3922.00	6.00
7	Accenture Plc	1.70	45908.00	4.00
8	Accretive Health, Inc.	1.80	1263.00	2.00
9	ACE Limited	1.70	28764.00	3.00
10	Acme Packet, Inc.	1.10	1601.00	4.00
11	Procter & Gamble	1.30	10952.00	5.00
12	Activision Blizzard, Inc.	1.30	12584.00	6.00
13	Adobe Systems Inc.	1.40	19078.00	9.00
14	ADTRAN Inc.	1.40	1275.00	5.00
15	Advance Auto Parts Inc.	1.60	5451.00	5.00
16	Advanced Micro Devices, Inc.	1.80	1943.00	5.00
17	Advantage Oil & Gas Ltd.	1.10	535.00	5.00
18	General Mills	1.30	2732.00	5.00
19	Kraft	1.30	657.00	8.00
20	BRF	1.30	1044.00	6.00
21	Aetna Inc.	1.20	16264.00	9.00
22	Affiliated Managers Group Inc.	1.40	7672.00	1.00
23	Aflac Inc.	1.70	24913.00	2.00
24	Dole Food Company	1.30	5028.00	5.00
25	Bunge Limited	1.30	880.00	5.00
26	Agilent Technologies Inc.	1.20	15413.00	5.00
27	Sysco Corporation	1.30	4846.00	5.00
28	Agnico-Eagle Mines Ltd.	1.20	8463.00	9.00
29	Grupo Bimbo	1.30	16535.00	5.00

For analysis, a screen dump below (Table 4) shows the excel sheet containing the list of twenty-nine potential suppliers. However, the approach will remain the same for profiling 1233 suppliers.

Tables 5-6 shown below represent the numeric values assigned to the industry type and country respectively.

Supplier profiling is performed through the process of cluster analysis. The result of cluster analysis groups the companies into three different categories (or clusters). The cluster 1 weight is 0.59, cluster 2 is 0.1 and cluster 3 is 0.31. Each cluster contains companies with similar characteristics. For instance, cluster 2 contains companies that belong to food and beverage industry, located in North America and

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Table 5. Numeric value for industry

No.	Industry Type	Numeric Value
1	Automobiles	1.1
2	Aerospace & Defense	1.2
3	Food & Beverage	1.3
4	Machinery/Industrial Goods	1.4
5	Pharmaceutical	1.5
6	Telecommunication	1.6
7	Logistics	1.7
8	Retails	1.8
9	Logistics	1.9

Table 6: Numeric value for region

No.	Region	Numeric Value
1	Africa	1
2	Asia	2
3	Central Asia	3
4	South East Asia	4
5	North America	5
6	South America	6
7	Middle East	7
8	Europe	8
9	Australasia	9

have high market capitalization. For example, JBS S.A, Nestle, Pepsico, Unilever, Procter & Gamble, General Mills, Bunge Ltd, Grupo Bimbo, Kraft, and Dole Food company belong to cluster 2.

Next, the suppliers are screened through ANP method to determine the top ranking ones(s) for collaboration. The ANP network consists of the alternatives 10 suppliers with criteria, sub-criteria and their relationships (or connections) with each other.

Figure 2 demonstrates an example of pairwise comparison matrix among the elements of the suppliers "compatibility" cluster with respect to element "collaboration possibility".

Final ranking of the suppliers is shown in Figure 3. The "raw" columns denotes the priorities from limiting super matrix, "normals" column represents the results normalized for each component and the column "ideals" present the results gained as a result of dividing the values in either the normalized or limiting columns by the largest value in the column. The number one ranked supplier is supplier Nestle. The top 4 suppliers selected for further screening through game theory includes Nestle, Unilever, Procter & Gamble and Grupo Bimbo.

Let us consider the collaboration scenario for one retailer and 4 suppliers. Four cost components for each partner (S_{xx}, O_{xx}, P_{xx}, T_{xx}) under each collaboration mode are used as inputs for the model. In Table

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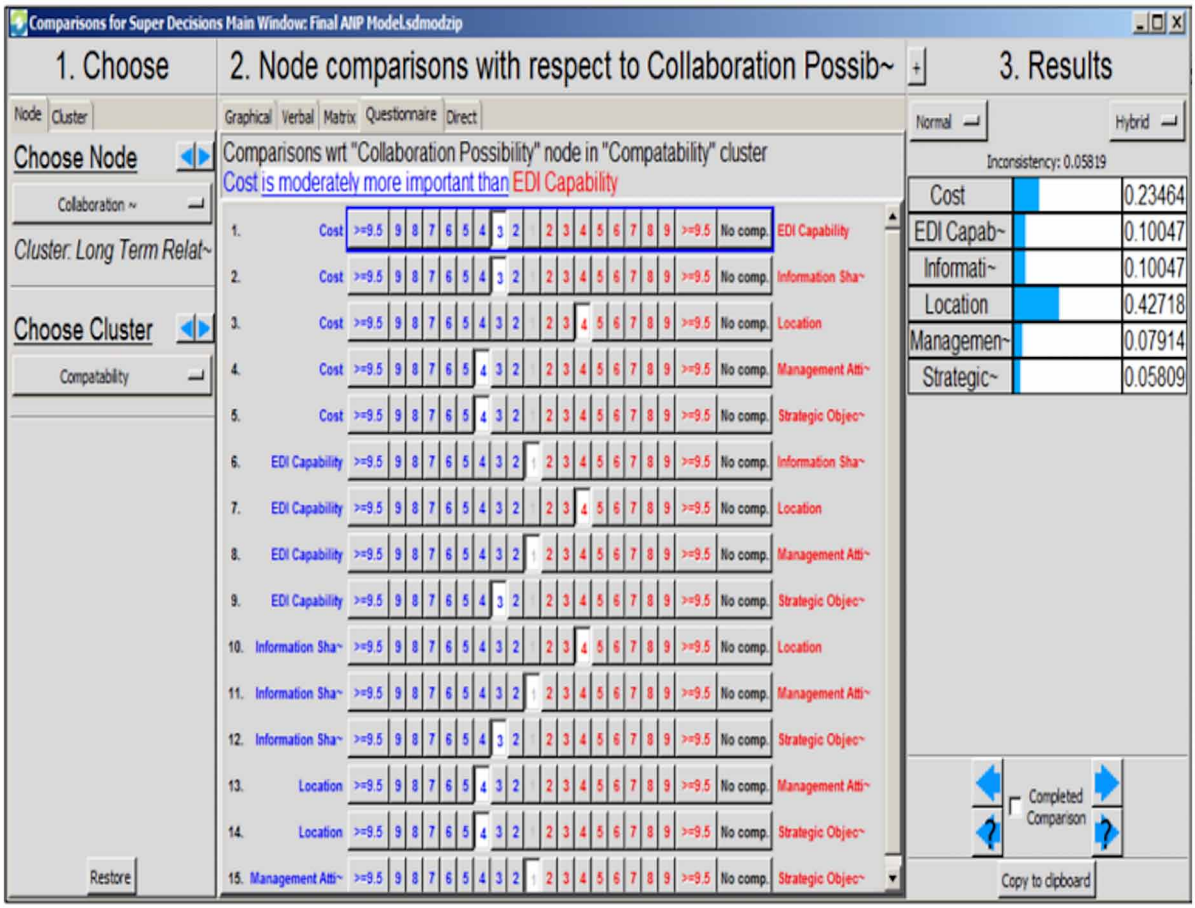
Figure 2. Pairwise comparisons between "compatibility" and "collaboration possibility



7, retailer 1 (R1) represent "Taylor Sons" and suppliers S1, S2, S3 and S4 represent Nestle, Unilever, Procter & Gamble and Grupo Bimbo respectively. Nash equilibrium analysis is performed. Since the example is considering only 4 suppliers and one retailer, it is possible to sum and compare the total costs. The likely costs to be incurred by the retailer and the suppliers as a result of going into collaboration are shown in the table 10. For instance, R1-S1 means costs to be incurred by the retailer as a result of going into collaboration with supplier 1. F.C, P.C, and N.C denotes the costs to be entailed by the retailer as a result of collaboration with supplier 1. In this case, R1 should go into "partial collaboration with supplier 1 since the total switching costs (16) is lowest in this mode. Similarly, S1-R1 means the costs to be endured by supplier 1 as a consequence of going into collaboration with retailer 1. . In this case, supplier 1 should go into "no collaboration" with retailer. This signifies that it might be profitable for retailer 1 to go into partial collaboration with supplier 1 but supplier 1 will be better off by accepting "no collaboration" option. Therefore, Nash equilibrium is not achieved in this case. However, with regards to R1-S2 and S2-R1, we can see that it is indeed "Nash equilibrium". The Nash equilibrium solution is highlighted in black. Based on the payoff functions, it is recommended that R1 should engage in full collaboration with supplier 2. On the other hand, it is also beneficial for supplier 2 to enter into full collaboration with retailer 1. This is the Nash equilibrium because supplier 2 is making the best deci-

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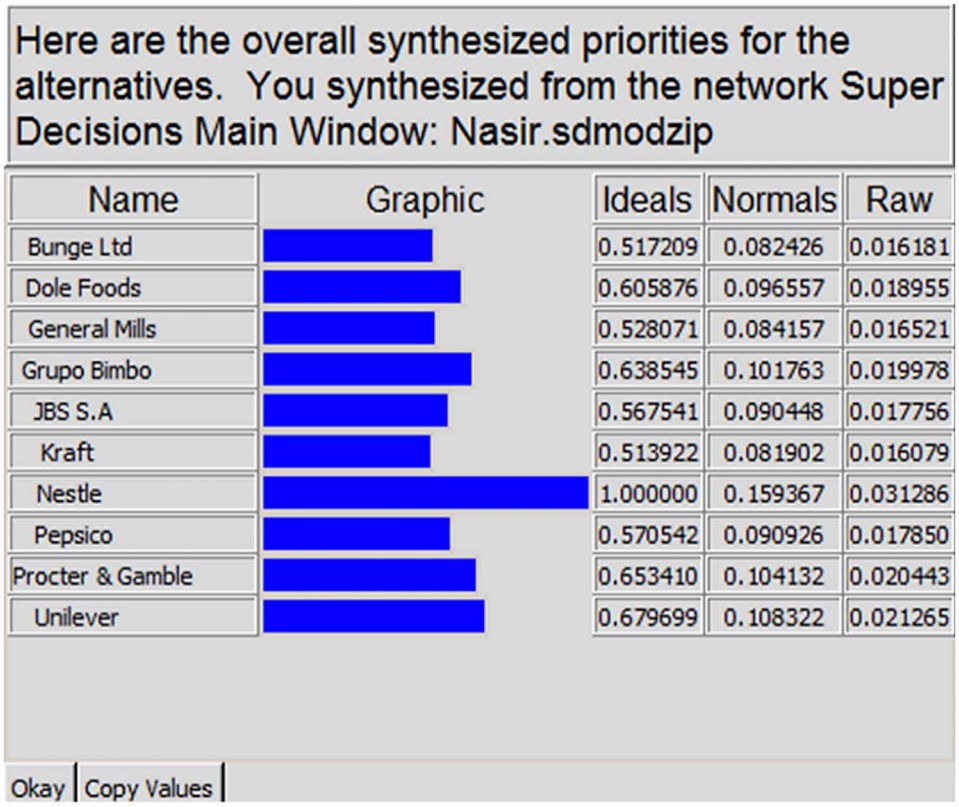
Figure 3. The synthesized values – the results for the alternatives



sion it can, taking into consideration retailer 1 decision, and retailer 1 is taking the best decision it can, taking into account supplier's 2 decision. Collaboration mode involving lowest payoff denotes that total switching costs required for entering into a particular collaboration mode by the partner will be less. Since, it has already been assumed that collaboration, be it partial or full, will ultimately result in net benefits for a particular partner. Hence, collaboration mode entailing lowest total switching costs will be the preferred choice for the partners. This collaboration model can be used for multiple retailer and/or suppliers. In our example, partial collaboration has been recommended to both the supplier and the retailer. We will determine profit allocation for this case using Shapley values.

The payoff function PF for supplier in a full collaboration arrangement with the retailer is given by:

$$\pi_{SF} = (p_s - c_s)q_s - \{(I_s + T_s + A_s + P_s + H_s) + \Delta C_{FS}/2\} \quad (14)$$

The payoff function PF for retailer in partial collaboration arrangement with the supplier is given by

$$\pi_{RF} = (p_r - c_r)q_r - \{(I_s + T_s + A_s + P_s + H_s) + \Delta C_{FR}/2\} \quad (15)$$

The costs related to inventory, administration, transportation, total switching costs, in case of partial or full collaboration, and production fixed costs are estimated for each partner. Costs for retailer (R) Taylor Sons and supplier S (Unilever) are shown in Table 8.

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Table 7. Expected output from collaboration

R1-S1	S_{xx}	O_{xx}	P_{xx}	T_{xx}	R1-S1	Total
F.C	400	400	100	200	F.C 1	1100
P.C	300	250	200	100	P.C 1	850
N.C	0	0	400	550	N.C 1	950

S1-R1	S_{xx}	O_{xx}	P_{xx}	T_{xx}	S1-R1	Total
F.C	460	110	200	100	F.C 1	870
P.C	220	200	110	100	P.C 1	630
N.C	0	0	340	200	N.C 1	540

R1-S2	S_{xx}	O_{xx}	P_{xx}	T_{xx}	R1-S2	Total
F.C	500	400	400	200	F.C 1	1500
P.C	550	200	600	260	P.C 1	1610
N.C	0	0	1100	600	N.C 1	1700

S2-R1	S_{xx}	O_{xx}	P_{xx}	T_{xx}	S2-R1	Total
F.C	600	200	200	200	F.C 1	1200
P.C	600	200	300	150	P.C 1	1250
N.C	0	0	700	650	N.C 1	1350

R 1-S3	S_{xx}	O_{xx}	P_{xx}	T_{xx}	R1-S3	Total
F.C	500	103	250	250	F.C 1	1103
P.C	300	200	250	124	P.C 1	874
N.C	0	0	300	150	N.C 1	450

S3-R1	S_{xx}	O_{xx}	P_{xx}	T_{xx}	S3-R1	Total
F.C	700	100	100	100	F.C 1	1000
P.C	400	100	140	100	P.C 1	740
N.C	0	0	790	200	N.C 1	990

R1-S4	S_{xx}	O_{xx}	P_{xx}	T_{xx}	R2-S4	Total
F.C	300	100	150	300	F.C 1	850
P.C	200	150	100	90	P.C 1	540
N.C	0	0	250	100	N.C 1	350

S4-R1	S_{xx}	O_{xx}	P_{xx}	T_{xx}	S4-R1	Total
F.C	500	100	220	100	F.C 1	920
P.C	300	100	200	100	P.C 1	700
N.C	0	0	350	400	N.C 1	750

Expected Output	**Expected Output**
R1 should do Partial Collaboration with S1	S1 should do No Collaboration with R1
***R1 should do Full collaboration with S2**	***S2 should do Full Collaboration with R1**
R1 should do No Collaboration with S3	S3 should do Partial Collaboration with R1
R1 should do No Collaboration with S4	S4 should do Partial Collaboration with R1

* Collaboration mode involving minimum payoff (lowest total switching costs) is recommended to each partner.

Table 8. Cost component

	Inventory Carrying Cost (I_x)	**Transportation Costs** (T_x)	**Administration Cost** (A_x)	**Production Fixed cost** (P_x)	**Total Switching Costs** (ΔC_x)	**Total Costs**
c(1) R	150	0	200	0	1500	1850
c(2) S	350	90	100	45	1200	1785
c(12) S-R	400	90	210	45	2500	3245

In ours results, we get c ({1}) = 1850, c ({2}) = 1785 and c ({1, 2}) = 3245. Now, there can be two possible orders of arrivals: (1) first retailer then supplier, and (2) first supplier and then retailer.

In case retailer comes before supplier, retailer's contribution is c ({1}) = 1850; when supplier comes the surplus increases from 1850 to c ({1, 2}) = 3245 and as a result, supplier's marginal contribution is c ({1, 2}) – c ({1}) = 3245 – 1850=1395.

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Table 9. Marginal contribution of players

Probability	Order of arrival	1's marginal contribution	2's marginal contribution
½	First retailer then supplier (12)	1850	1395
½	First supplier then retailer (21)	1460	1785

In case supplier arrives first before retailer, supplier's contribution is c ({2}) =1785; when retailer comes, the surplus increases from 1785 to c ({1, 2}) = 3245 and as a result, supplier's marginal contribution is c ({1, 2}) – c ({2}) = 3245 – 1785=1460. Therefore, retailer's expected marginal contribution is $\frac{1}{2}$ x 1850 + $\frac{1}{2}$ x 1460 =1655 and supplier's expected marginal contribution is $\frac{1}{2}$ x 1395 + $\frac{1}{2}$ x 1785 = 1590.

Therefore the Shapely values are x_1 =1655 and x_2 = 1590. The Shapely Values denote that retailer (Taylor Sons) and the supplier (Unilever) need to pay 1665 and 1590 respectively in order to enter into full collaboration with each other. Table 9 presents these results.

CONCLUSION

In this chapter, we present an ANP and Game theory based approach for modeling collaboration planning in supply chains. Three major decisions related to collaboration planning namely partner selection, collaboration strategy selection and profit allocation among the involved partners are addressed. A numerical application is provided.

Based on the current work, several future extensions are possible. Firstly, the proposed framework can be extended by integrating collaborative planning, forecasting and replenishment (CPFR) approach. Secondly, estimation of components of the total switching costs for each partner can be done from practical point of view. Currently, the total switching costs are assumed to be in numbers. In reality, these numbers represent the additional amount a particular partner has to spend in order to update its systems and processes to be compatible for collaboration. Hence, these costs can be considered as non-integers in the form of "high", "medium", or "low". Thirdly, the collaboration model can be further developed to incorporate expected net benefits such as cycle time reductions, service level gains, inventory and product cost reductions to be realized as a result of going into any of the three types of collaboration. The expected benefits can then be compared with the total switching costs for calculating the net benefits for each of the three types of collaboration. Lastly, the framework proposed in the study is from retailer and supplier industry's point of view. Through bibliography research, more partner selection factors such as safety, packaging, aesthetics, maintenance and reliability can be added so as to allow the framework to be applied to problems in a variety of areas and industries.

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Chapter 27
Evaluation of Make or Buy Approaches for Batteries Used in Electric Cars:
A Comprehensive Make-Buy Analysis With Qualitative Factors Defending the Decision to Make Batteries

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ABSTRACT

The electrification of the vehicle has led to fundamental changes in the automotive value chain. Resulting in original equipment manufacturers (OEMs) to decide between manufacturing in-house and source the either product or component from joint ventures or suppliers. As electrical vehicle differs fundamentally from fuel-based counterparts, OEM must be adaptive with their manufacturing strategies. The value creation in the design is the replacement of engine-gear system with battery. Hence, battery is the critical component to be considered in manufacturing strategy. The decision making in finding less expensive and profitable way of either making the product or buying components from a capable supplier in global competitive environment is a serious discussion. In this chapter, the author is studying and applying the make or buy strategy to Tesla battery production.

INTRODUCTION

The automotive battery, the energy counterpart of the electric car is the single most motivational commodity that must be considered in proposing a strategy for manufacturing. Not only cost, but it determines the features of the car. For a potential supplier, it is important to evaluate the parts – intermediate or all the battery they want to focus in the value chain and which parts will be sustainable to keep for the original equipment manufacturers- known as OEM. This evaluation should occur before supplier strategize for

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batteries, site locations planning and production set and ramp up. Such decisions are important not only for their future position in the value supply chain but also to normalize the financial economics.

The manufacturing of battery involves high capital investment, which further entails to the set up and maintenance of supply chain of raw material. This is another reason why batteries are termed as cost drivers of any electric vehicles. Thus, it is foremost to assess the different make or buy strategies to produce and expand electric vehicles to the market. The financial implications are heavily influenced by battery manufacturing costs directly proportional to driven by economies of scale, which further fluctuates because of the volume uncertainty due to uncertain market conditions and development. Due to the hazy innovations in unleashing battery technology lead to investment risks as producer does not want to bid on less promising bid. Due to dynamic market conditions and non-exempted adaption to the changes due to continuous improvement and development of the electric vehicle, the position of the producer change and evolve over time. The production model whether vertical integration or partial integration is followed must be evaluated as well. (Huth et al., 2015). The model proposed in this paper is evaluating the battery value chain and other possible derivatives such as customer experience, supplier base, innovation in technology and architecture important to design strategies and further subject to financial implications and dynamic market conditions and other existing uncertainties. The author's focus is to study the influence of volume uncertainty on the economies of Scales, the financial values of a technology leap, level of engagement, and impact of change in the value chain over time in overall contribution model. The goals of this paper are -

- To study the manufacturing process at America based electric car producer and their core vision.
- To study the advantages and scope of improvement in established manufacturing set ups.
- To apply Make or Buy Analysis over Battery business.
- To choose the applicable Make-Buy framework and apply to qualitative factor to conclude the decision.

Literature Review

The value chain of the electric vehicle batteries is phased over two important steps – Process 1: Cell manufacturing Process 2: Battery packaging. Each of these processes includes sophisticated engineering and demands effective capabilities. For example, Cell manufacturing, unlike solar cells, requires complex and layered technological skills for the controlling of the electro-chemical body. Not all manufactures possess either the competency or capability to produce. On the contrary, battery packaging has most similar practices across the industry. Packaging is assembling of fabricated parts. And setting up a facility for the cell manufacturing and automation involved in the ramping up production in such facilities is also a considerable value addition to the investment. Above all, the economies of scale reduce the cost in the long run as it reduces the fixed costs due to efficient utilization and capacity rates. The flow chart in Figure 1 presents the value chain of Battery.

Figure 1. Battery value chain

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As per the comprehensive analysis on the trends followed in make-or-buy strategies by major producers concludes that engagement of the manufacturing supplier can be summarized in two ways. 1. Full ownership - Manufacturing as well as battery packaging 2. Joint ventures with specialized electrical or chemical domain companies to contributes competencies and segment the risk. The joint venture generally promotes flexibility over technologies and thus related expense. Such collaboration in the business allows manufactures to change their position in the value chain according to the varying market behavior. For example, few manufactures in the recent time have increased their market share of battery production whereas some have reduced their share and offering due to non-survivability in front of changing requirements. (Berdichevsky et al., 2006). The market of electric cars is evolving, and it requires the dynamic evaluation and adaptation of thus produced uncertainties and development. This is a supporting answer to conclude that why economies of scale do not suffice the decision.

As Volume estimation in manufacturing is based upon customer requirement, risk pooling in the supply chain and cost advantage due to desired utilization rate and unavoidable initial investment. Recent development in the area of the battery technology have witnessed technology leaps which means new technologies invented considerably different from the previous dominant technology. The same leap can be expected from the development in the lithium ion battery technology, which will surely result in the modification of the battery manufacturing processes. Investment and additional operational cum maintenance cost are also always evolving. (Stringham et al., 2015). Hence, before designing the decision support system, several challenges are considered. Firstly, the degree of possible engagement in the production of battery cells as well as packs. Secondly, the position in the value chain which can vary depending on the market development. Thirdly the profits from the volume-dependent economies of scale, and at last possible interdependences between manufacturing processes. These factors are compared over volume and technological uncertainties for make or buy- decision. There are different types of approaches based on quantitative or qualitative factors for a decision support, in which Make-or-buy decisions have been extensively discussed in academic as well as professional practices. This method is extended with an integration to approach strategic value assessment used in this chapter to choose among Make or Buy.

BACKGROUND

Company studied in this chapter is a maker of high-end, high performance premium electric vehicles in the World. Their core strategy is to prove electric vehicles are both stylish and efficient and Agenda is production of low-cost premium electric vehicles for mass adoption. They also the producer of clean energy generation and storage product such as Powerwall, Powerpack and Solar roof. Battery is the ultimate energy solution, hence called core strategic product. Company has dedicated a high-tech facility for its mass production – called Gigafactory in Nevada US. This facility has enabled the production of batteries in terms of KWH more than of existing competitors combined. In 2018, the annualized rate of roughly 20 GWH has been achieved. This company aim high returns with economies of scale, high adaptability & flexibility to innovative manufacturing, cost of battery/unit and total cost and integrated and optimized manufacturing processes under one roof at Gig factory. Their recent releases have marked a success and they are continuously designing and redesigning their vehicle for increase in sales. It has been largely debated in the business media to choose the flexible, agile and dynamic to change option in developing strategy for any component or sub-component of product in the production. Due to the variable risk and overheads associated, market either automobile or any other industry is gradually

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moving or increasing reliance over supply-chain and vendor system as it creates valuable partnerships, exchange of knowledge and innovation.

Though such exchanges among partners are subject to their proprietaries, business contracts and MOU's, but still flexibility outweighs over rest. But for few organizations and businesses, that is not all or least important. When it comes to core components in the product, companies do go through aggressive due diligence processes and external domain expert consultation in order to reach the right decision around core component placement in the whole production management. As in this chapter, author has considered the business case of electric car producer leader and their giant global market share. Further Author is recommending the solution for their core product – which is battery management in this book chapter. Author's motivation to defend how less flexible and expensive implementations sometimes according to the nature of business, helps organization to become independent and proprietor of their own businesses, which makes them leader.

MAIN FOCUS

Problem Description

The supply chain in any automotive industry is around Purchasing – Supplying – Receiving – Fabrication – Assembly – Distribution. However, it is majorly impacted by uncertain market development, uncertain product volume, uncertain evolution and high investment risk. In all these acting attributes, the main agenda remains the same, which is to produce vehicle at competitive price with optimum quality. In this scenario, it is contested to choose between battery production or battery purchase from capable supplier in the car production. We will conclude our recommendation by applying strategy using strategic value framework and analyzing the pros and cons of Make or Buy at each qualitative factor. A make or buy analysis is an integral part of most manufacturing companies. Companies must decide between manufacturing different components of their products in the house or purchasing them from an external supplier. A make or buy analysis looks to compare the costs and benefits associated with manufacturing the products or components of the product in their own facilities verses the costs and benefits of contracting an outside supplier to procure such items. (Cruz-Cázares et al., 2013). There are many advantages and disadvantages to outsourcing which necessitates that a comprehensive quantitative and qualitative analysis must be carried out prior to undertaking this decision to be able to fully justify and support this decision. A make or buy analysis considers several important factors such as the availability of technological and the associated costs of production and the capabilities of the manufacturing facilities to produce at the required levels. Step by Step Guidelines to a Make or Buy Decision

1. Define the objectives
2. Identify all possible options
3. Carry out a quantitative analysis
4. Carry out a qualitative analysis
5. Factor the qualitative aspects into the quantitative aspect
6. Arrive at a final make or buy analysis

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Quantitative Factors

After clearing defining the company's objectives and identifying all potential options, the first step is to carry out a quantitative analysis. This is done by comparing the expenses associated with every potential option. The cost of manufacturing an element or component in the house include both variable and fixed costs. The cost of new machinery or assembly lines fall under fixed costs. The costs of a 'buy' decision include purchasing, ordering, holding and unavailability costs. There are many other cost related elements to a make or buy analysis. Such elements must be fully comprehended and accounted for to be able to produce a comprehensive and reliable make or buy analysis. The costs associated with producing an element in the house include the cost of production material as well as the labor costs for producing these items. In addition, storage costs and disposal costs of miscellanies and by-products from the production process must be accounted for. Most importantly, the costs of the buying the production equipment and their maintenance must be taken into consideration. Buy costs include the total price of buying an product or component. These are costs are divided into 4 sub categories:

1. Purchasing Costs - cost of an item is the unit purchase price from an external source including transportation and freight costs.
2. Order Costs - costs are the administrative costs of issuing a purchase order. These costs include analyzing different price quotations, writing purchase orders and inspecting materials.
3. Holding Costs - costs of holding the material. These include storage costs, handling, deterioration as well as the opportunity cost of holding up the money which could have been otherwise invested.
4. Unavailability Costs- These are the costs that arise when the desired material or component is not available at the right time. This is known as 'stockout' or 'depletion cost' in the manufacturing industry. Shortages in the material or elements in the assembly line could delay the work progress as well as waste labor resources that would find themselves idle in such a scenario.

Qualitative Factors

In this section, all non-quantitative factors that can have an influence the decision to make or buy is studied under the qualitative analysis. Such factors include the availability and reliability of the suppliers, the technological of the company, the design of the product and the strategic importance of the element or component in question. Companies cannot afford to outsource part certain elements that are a core component of their business as to not lose their competitive advantage in the market. The factorization the qualitative factors into the quantitative aspect are monitored. The less expensive option may not always be the best option in the long run. For example, it might be cheaper to produce a certain component in the house, however this component might be of lower quality than that which is procured from an external supplier. At first, a make or buy analysis can seem as a purely quantitative analysis between the costs of internally producing the item verses buying it from an outside supplier. However, the reality of the matter is that a make or buy analysis involves many qualitative issues that may completely overrule a number analysis of production costs. A numerical analysis would not be meaningful if it is not preceded by a comprehensive qualitative make or buy analysis that looks at issues such as the strategic importance of the element in question as well as the expertise of the company. Hence in this study, as part of a qualitative make or buy analysis, The author has carried out a strategic value assessment of company's decision to make its own batteries in the house.

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Problem Analysis

In this section Company's decision to make their lithium ion batteries is analyzed following the SVA framework. The strategic value framework is utilized to do a complete comprehensive qualitative make or buy analysis. The utilized framework consists of levels that can be used as a guide to make a correct choice on whether company should make or buy its own batteries. The SVA identifies the 5 criteria that have the largest effect on any company's decision to make or buy their supplies. The following section is structured as follows. (Fine et al., 2002). For every criterion, the definition is presented and how it affects the make or buy decision is explained. Finalized Strategic Value Assessment (SVA) Criteria:

1. Customer Importance
2. Technology Clock speed
3. Competitive Position
4. Supply Base Capability
5. Architecture

By studying the criteria listed above, the strategic value of a certain element or component can be studied, and a decision can be made. In general, high customer importance and fast clock speed indicate high strategic value and provide a good argument for insourcing. A strong competitive position can be lost if a company decides to outsource a major core component of its work. To be able to efficient outsource and not worry about high unavailability costs and un reliability, the suppliers must be capable in ensure successful outsourcing. The last thing that needs to be considered is the architecture of the product. The more modular the final product is, the easier it becomes to outsource some elements of it. After studying these aspects, a logical decision can be made around – insourcing, outsourcing, partner/acquire, partial insource, partial outsource, invest spin off and develop suppliers.

Ideal Battery Original Equipment Manufacturers (OEMs)

The global automotive industry is about to enter a period of wide-ranging and transformative change, as sales continue to shift, and environmental regulations tighten. Companies that want to have a successful, long-term future need to get key strategic decisions about their strategic components. For Example Battery for a electric car company. To buy any product from the supplier (OEM) in the market, Industry features the following key qualifications to investigate the supplier (OEM) before beginning the procurement or business. These key features OEMs need to address to get a piece of future profitability. Company do agree to this consideration.

- Complexity and cost pressure: There will be more platform sharing and more modular systems. At the same time, regulatory pressures will tighten, and prices in established markets are likely to be flat.
- Diverging markets: OEMs need to adapt to changing regional and segment patterns of supply and demand with respect to their production and supply base footprints, supply chains, and product portfolios; and the emerging market offers new growth opportunities.
- Digital demands: Consumers want more connectivity, are focused on active safety and ease of use, and are increasingly using digital sources in making their purchase decisions.

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- Shifting industry landscape: Suppliers will add more value in alternative powertrain technologies and in innovative solutions for active safety and infotainment.

To be qualified as OEM for this company, supplier not only need to match the progressive growth plan but also to find profit from these challenges in order to mitigate their risks. Fact to consider is OEMs cannot spin their traditional toolbox over continuous fluctuating and changing demands. They need transformation to adjust their strategic priorities, deploy the appropriate investments and resources, and develop new skills to execute the evolving strategic objectives of this company.

Analytic Hierarchy Process (AHP) Method

SVA is the primary method focused and entailed in this chapter. AHP is introduced here with a limited scope to shed light on qualitative factors studied by other researchers in their respective AHP experiments. (Minh, 2011). These factors were considered to check the inclusiveness of the SVA method applied and elaborated in this chapter. Discussion on AHP method and its algorithm below sets the standard for other techniques to be followed and further helps author to keep SVA in check for its applicability in doing the defense.

The goal is to find less expensive and superior way of either making their product or buying components from a capable supplier. The decision making on whether the company should produce crucial components in-house or outsource them is based upon transaction costs and product strategies from various discussions within the company. The Critical Factors are: -

- Transaction costs
- Vertical integration
- Purchasing
- Operations research

The strategic models are generally built in the traditional cost and strategic point of view, which is difficult to apply in real world practical problems. An empirical formula, which would help us to determine important factors is possible through AHP. AHP Algorithm is stated as follows -

Step 1: Problem decomposition: Arrange a hierarchy of main criteria & each main criteria is further decomposed into sub-criteria etc. The decomposing process is done until the lowest of the hierarchy is reached.

Step 2: Comparative analysis: The relative importance of each main criteria and sub-criteria at a level are measured by the procedure of pairwise comparison. The decision makers provide numerical values for the priority of each criterion using a rating scale. The relative importance of each factor is rated by a measurement scale that decision maker provides with numerical judgments.

Step 3: Synthesis of priority: The priority weights at each level are computed using an eigenvector or least square analysis method. The process is repeated for each level of the hierarchy until a decision is finally reached by overall composite weights.

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Figure 2. AHP criteria and sub-criteria

Provisions	Main Criteria	Sub- Criteria
Facility	Supply chain management & logistics Strategy	Flexibility in product demand fluctuation
Battery Minerals		Stable Supply
Other Raw Materials		On time Delivery
Manufacturing Technology	Core and Strategic Product	Core and Strategic Component
Product Strategy and Quality		Competition
Architecture		Market Control and Risks
Innovation		Quality Management
Proprietary		Innovation management
Resource Capability & Availability	Vision and Long-term goals.	Skilled Personnel and Operational training
Business Automation		Cost Competitiveness
Supplier base		High end premium cars
Investment		Transaction cost.

Considering the algorithm above, the following criteria and sub criteria of the firm's business model can be considered for evaluation of Make or Buy Decision. Figure 2 presents the provisions, main criteria and sub criteria considered in assessment from AHP method.

As outlined in the beginning of this section, AHP's result are not used in recommending any solution in this chapter. Its approach is only studied at high level to compare the factors studied and to verify the comprehension of SVA method.

SOLUTION

Customer Importance

Customers play an important role in the creation of supply chains. The customer is a key figure in the supply chain and their needs, values and opinions will affect the supplier decisions buyers make. Corporate success, at this company and elsewhere, begins and ends with customer satisfaction. For battery manufacturing, customer preferences can be estimated in part by observing buying behaviors. (Fine et al., 2002). That is, we can tabulate which kind of the electric battery that the customers like most and ask the customers the reasons about why they like or not. We must elicit customers' tastes on performance characteristics such as fuel economy, acceleration, and quietness (noise, vibration and harshness) and then relate those to systems and value-chain process elements. This section is divided into two different classes of consumers. The first is SUV customers, and the other is small car customers. For SUV customers segment, like model 3 long range and model X 100D they should focus on the acceleration and smoothness of their cars. The main purpose of SUVs is driving off-road and in difficult terrains, braving elements of weather along the way. For this reason, SUVs come with power, force and capacity. So, the battery should have more powerful because the SUV would consume more battery and the battery should keep a longer time. (DeBord, 2017). And on the other hand, for SENDA customers segment, like model S 100D they should pay concentrate on the cars' speed, available and the battery life.

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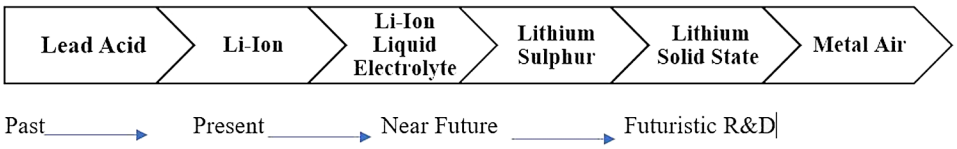
Figure 3. Battery technology proposed roadmap



Therefore, the battery should be fast and charging speed. And they also pay much more attention to the layout of the vehicle's interior space than to any engine characteristics, so the cost is another important element for them to consider about. To implement the customer-importance component of the model, we should conduct workshops with engineering and manufacturing staff, relating engine and battery subsystems to various performance characteristics perceivable by customers. we also need conducted clinics with customers to build a statistical model, capturing their preferences. The resulting model aids in understanding what product characteristics the customer will trade off or pay for at a premium.

Technology Clock Speed

This electric car leader is continuously evolving design and experimenting with redesign of its value chain in order to continually find sources of maximum advantage. Figure 3 presents the proposed roadmap of battery technology.

From the lead acid-based battery to Li-ion battery technology, company has wheeled an automobile industry on new innovative, sustainable speed. The demand shows that it made the preferred customer segment. The business model of this company is focused on continuous development and research. Despite the conforming battery product, This company is investing in research of optimized battery technology solutions. Li-Ion Liquid Electrolyte based battery vehicle is in verification stage. The production would start if prototype passes the inspection and meets the objective, quality and cost criteria. The research is on for Li-Ion higher voltage battery. Now, When firm is open to innovation, continuous innovation leads to variable product. Firm is achieving 30% improvement in volumetric energy density within 2 to 3 years. Target to achieve and maintain clock speed in technology improvement in future years. (Pressman, 2017).

Lithium Ion – Paradigm shift from 18650 to 21700: 21700, a cylindrical lithium battery, in which 21 is the diameter in mm whereas 70 is height in mm and 0 denotes the cylindrical type battery. Model 3 has these larger cells. Model S and Model X, which have cells known as 18 650 - 18mm in diameter and 65mm long)

- Energy density 21700 is higher than 18650 and cost of pack is reduced. The absolute performance of 21700 is better as bigger cells enabled the producer to optimize volumetric energy density.
- 21700 has 2 important core features. Improved Monomer and group energy density. The cell capacity can reach 3 ~ 4.8Ah, with significant increase of 35%, in a group and the energy density is increased by 20%. 21700 Chemical innovation is unique, not off the shelf product.

18650 battery cells are manufactured by Panasonic. But Company dedicatedly, is innovatively changing the chemistry of the cells with 21700.

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Core Chemical Composition Change

Decrease of cobalt content per battery pack and increase of nickel content while maintaining superior thermal stability. At present, the cobalt content in Nickel-Cobalt-Aluminum (NCA) cathode chemistry is already reduced lower than next-generation cathodes based on Nickel-Manganese-Cobalt with ratio of 8:1:1- method to be used by other cell producers. Reduction in cobalt composition is an achievement. Why? Company has reduced the amount of the cobalt in the Model 3 cell's cathode. It is an achievement as Firstly, Cobalt prices have more than doubled over the year. (Berdichevsky et al., 2006). Reason is high demand. Demand for cobalt has increased significantly since it is used in several different types of battery cell chemistry. The demand for battery cells has increased due to the rise of electric vehicle and energy storage systems. Secondly, Won of ethical dilemma over cobalt's' primary sourcing location. Democratic Republic of the Congo (DRC) is accounted for more than 50% of cobalt supply in the world. The cobalt mines there is known for corruption and human rights violations due to child labor. Company's target is to transition from Non-significant cobalt usage to cobalt free battery cells from last 6 years, Company has reduced the average amount of cobalt used in its vehicles by 60%, from 11 kilograms to 4.5 kilograms per car. Research and development in the material development areas with target towards higher-energy, lower-to-no-cobalt chemistries. ("Cobalt Consumption by 60%," 2018). Company emphasize the nickel-cobalt-aluminum (NCA) technology developed by Panasonic whereas other EV competitor are nickel-cobalt-manganese (NCM)-focused Company has used NCA cell chemistry for long range vehicles and NMC for utility storage products. With consistent improvement in technology, cobalt content has been reduced in both cases. Momentarily, Competitive Technology that may act heavy is NCM with 8:1:1 cathode material. Company is mastering the counter solution through Nickel-cobalt-aluminum (NCA) technology, which requires less than a third the amount of cobalt. It is already lower than next-generation cathodes, which ensures company's dominant strategy.

Challenge in Developing Cobalt Free Batteries

- Life Cycle of Cell: Cobalt is the safe element in the cathode and directly proportional to the life cycle of the cell. According to the current market standard, eight-year is the warranty period to retain 80 percent of the original capacity of the battery. Need to test that cobalt free battery can ensure the warranty period. Otherwise, maintenance or replacement is way more expensive than the savings using less cobalt. ("Cobalt Consumption by 60%," 2018).
- Overheating Risk: Increase of nickel may result in overheat and it can no longer effectively cool itself without cobalt. It may lead to severe combustion. Though relatively lower but unavoidable risk.
- Special Environment: The low-cobalt formulations need to produce in special dry environments, which has an associated cost.
- Present: The work on cobalt-free battery is under progress by Panasonic. But for now, Cobalt is getting used in reduced composition (21700 form) to match the received production demand. The EV producer has reduced its cobalt needs by 59% on average per vehicle.
- Continuous Innovation: The next generation is something like solid-state batteries with the solid anode are not around the corner in near future. Other things, like sodium-ion batteries, are still on the lab scale and would need transition from lab model to research to pilot testing, to cathode testing to battery testing.

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Auto-Tech Comparison

First, their battery is a unique chemical proprietary. Second, the weightage associated to factor such specific power, safety, performance, life span and cost is different than competitor companies such as Nissan and BMW. On the one side, the experience from successful BMW and Nissan battery outsourcing is available for the learning. (Bartlett, 2019). On the other side, their technology framework with less information and continuous evolvement is observed with high risk. Model S battery is twice the energy density of than of Nissan leaf, difference in range is more than double. When it comes to factors such as drag coefficient, weight, motor efficiency, rolling resistance, this company stands out in comparison with Nissan and BMW.

Other Technology Changes

- All-Wheel Drive Dual Motor: Conventional all-wheel drive cars employ complex mechanical linkages to distribute power from a single engine to all four wheels. This sacrifices efficiency in favor of all-weather traction. In contrast, each Model S motor is lighter, smaller and more efficient than its rear wheel drive counterpart, providing both improved range and faster acceleration. With two motors, one in the front and one in the rear, Model S digitally and independently controls torque to the front and rear wheels. The result is unparalleled traction control in all conditions.
- Autopilot: Autopilot combines a forward-looking camera, radar, and 360-degree sonar sensors with real time traffic updates to automatically drive vehicle on the open road and in dense stop and go traffic. Changing lanes becomes as simple as a tap of the turn signal. When driver arrives at destination, Vehicle to detect a parking spot and automatically park itself. Standard equipment safety features are constantly monitoring stop signs, traffic signals and pedestrians, as well as for unintentional lane changes.
- Design with Endurance: Their design and engineering teams have gone to extraordinary lengths to ensure that air flows smoothly above, around and below vehicle to reduce drag, which in turn maximizes battery range. The smart air suspension lowers the car's height at highway speeds to reduce its frontal area. Electronically controlled vents stay closed until sensors detect that cooling is necessary. The front bumper routes air uninterrupted beneath the battery's flat skid plate and past the rear diffuser.

  The cabin combines meticulous noise engineering with its uniquely quiet powertrain to obtain the sound dynamics of a recording studio. The gem of the interior is the 17-inch touchscreen, which is angled toward the driver and includes both day and night modes for better visibility without distraction. It puts rich content at your fingertips and provides mobile connectivity, so you can easily find your destination, favorite song or a new restaurant.
- Zero profile door handles: When a key is in proximity, they automatically extend. When no longer in use, they retract into the body of the car, creating a seamless surface for air to pass over.
- Charging: Approach the driver's side taillight with a charging connector and the hidden charge port automatically opens. The charging connector cannot be removed until Model S is unlocked.

These are general automobile smart feature available in most vehicles. However, this is written here to be reviewed as features that increases the performance load on the batteries unlike other fuel dependent vehicles. Their centralized, integrated, technology driver architectures enable flexibility and over the

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air software upgrade ability across the entire domain. Decentralization control units created complexity and incompatibility. The points to note here are -

- The vertical integration in this company for battery production is justified.
- Any procurement of non-strategic non-core component in the form of Quasi-integration (join venture) with majority of control can also be considered to speed up the production. This does not apply to battery.
- Battery is most strategic, impacted by several factors such as where the company's intellectual property is focused and where the company's technology roadmap projects

Hence company can think of outsourcing body in white components than core strategic product such as battery.

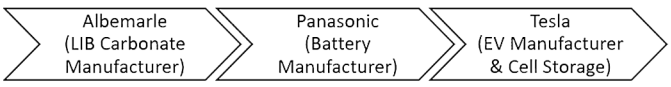
Competitive Position

Competitive position is a firm has already acquired or is trying to acquire the market share position, relative to its competitor. A strong competitive position makes a firm an advantage over its competitors, thus allowing it to retain/attract more customers, and gain more market share and profits. The advantage, competitive advantage, is a company owns over its competitors which promotes more products sales or revenue gained. The company has an edge over others as which it can intensify the advantageous elements, areas of relative competitive strengths as candidates for insourcing, internally with significant effort or investment. Additionally, strategic advantages are often achieved as well when an enterprise is to insource those elements in value chain with a relative competitive advantage. So, the stronger one's own competitive position in designing or manufacturing the value-chain element, the more desirable it is to insource it. There can be various forms or ways of competitive advantage like cost-efficient production/supply system, patents and an advanced distribution network, etc. (Howard, 2014).

They conduct vehicle manufacturing and assembly operations at the facilities in Fremont and Lathrop, California; Tilburg, Netherlands, and its Gigafactory runs as a centralized facility to work together with their suppliers to integrate battery materials, cell, module and pack production, near Reno, Nevada. It presents some participations cooperating with firm in its supply chain of cell production and storage business below. The flow of battery manufacturing unit is presented by Figure 4.

Their core competencies are powertrain engineering, vehicle engineering, innovative manufacturing and energy storage. It has upgraded the battery from 18600 cell made for Roadster, Model S and Model X to 2170 cells for Model 3 with high cell store and cost advantage. The whole vehicle manufacturing and assembly of supply chain are operated through factories in Fremont, California; Lathrop, California; and Tilburg, Netherlands. Gigafactory as discussed can facilitate the total battery production and plan to reach 70% of cell production capacity built in facility by year 2020. They have executed the procure-

Figure 4. Battery manufacturing units



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ment successfully with Panasonic to purchase at least 1.8 billion lithium-ion battery cells at preferential price from 2014 through 2017, has continued for now. It is obvious to conclude that battery technology and battery manufacturing are strategic, and core advantageous processes of them involves considerable effort, investment and competitive strength with respect to battery production market.

Battery Technology

They maintain safety, reliability and longevity and designs the battery packs to achieve high energy densification at a low price. Their proprietary technology has unique features such as high energy density, charge balancing, cooling, structural durability, safety and electronic management system. High quality with low cost in manufacturing is achieved in the form of large volumes of battery packs through advanced technologies. For the expertise in the safety and energy management systems requires efficient use of lithium-ion cells for automation, which internally require active collaboration with vendors to further optimize cell designs for seamless performance and quality factors (Young et al., 2013).

18650 Cells: They have been using 18650 cells manufactured by Panasonic for Model X and S cars since 2013 in Asia. These are small batteries cells and are slightly larger than standard AA cells. Panasonic designs, integrated in their circuits are referred as most stable energy composition and solution available now, which assures long-life, reliable performance in demanding automotive sector. Features include cylindrical cell is 18 mm in diameter and 65 mm in height. Initial they designed battery packs containing 18650 batteries could store up to 85 kWh of energy. Followed with noticeable configuration changes resulted from continuous development were made in the design of anode, which increased battery capacity by about 6%, enabling the battery pack to store up to 90 kWh of energy. The recent innovative changes made in the internal structure of the battery pack, has increased the storage up to 100 kWh of energy, allowing vehicles to travel over 300 miles.

21700 Cells: Cell is called 21700 as its specifications are 21 mm in diameter and 70 mm in height initially designed for Powerwall home storage products and Powerpack utilization storage products. The volume of 21700 cells is 46% larger than 18650 as well as 10-15% more energy efficiency than 18650. The cost of their battery cell is at $111 per kWh less than the second-best LG Chem, at $148 per kWh. Control of battery resources and production are keys to electric vehicle leadership. They take this leadership with commitment towards high performance and cost-efficiency.

Battery Manufacturing and Assembly

The facilities through which their entity functions are responsible manufacturing and distributorship of all products to all customers in all markets inside of the United States and Europe. This is supervised by corporate and regional sales services and administration department. Factory includes casting & stamping, machining plastic fabrics & body assembly, seat assembly & vehicle assembly, end-line testing and other manufacturing links. (Berdichevsky et al., 2006). These operations are supported further with lithium-ion battery packs, motors, gearboxes and other components for cars at their factory. The investment is made for the required flexibility in accommodating multiple products and plans to expand battery cell production lines with the partner Panasonic to meet the expectation of 500,000 vehicles annually by 2020. However, this evaluation makes author to recommend vertical integration in manufacturing process.

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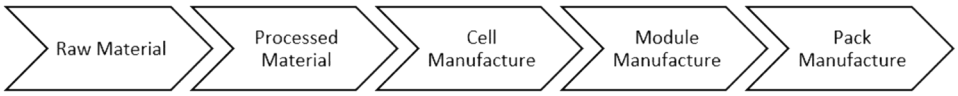
Figure 5. Battery manufacturing processes



Battery Assembly: A lithium-ion cell production involves its own supply chain beginning from mining raw materials to convert them into energy stored for a wide variety of applications. The supply chain can be seen below: -

Step 1: LIB production machines/plants manufacturing
Step 2: Renewable LIB utilization
Step 3: Recycling materials related to cell production

Figure 5 presents the high level of battery manufacturing processes.

As discussed, their mega investment called Gigafactory has substantial utilities and high automation to run the battery modules and battery packs production under one roof. Panasonic profound partnership with them at Gigafactory to invest in initial manufacturing equipment used in cell manufacturing weighs the execution. (Lambert, 2018). In 2018 Gigafactory I battery production has already reached a mark of annualized run rate of roughly 20 GWh, making it the battery plant with highest turnover in the world by a significant margin. Hence, they produce more batteries in terms of kWh than all other carmakers combined. Reason – Their higher battery pack, 75 to 100 kWh on average is much more than inter and intra segment automakers combined. So, it is summarized that this organization leads absolutely in the battery technology and battery manufacturing and critically, needs to maintain its position in the market prone to constant influence by competition, technological changes and market demands.

Supply Base Capability

The supply base capability is a critical parameter in the strategic value assessment. A very important consideration in the strategic value framework is the availability of capable suppliers for the given value chain element. The strategic value assessment states that stronger the current supply base the less risky it is to outsource. This section is divided into 2 parts. The first is the availability of technically competent suppliers who have a proven track record of meeting their contractual obligations, meeting the specifications and delivery times agreed upon. The second issue that must be considered is the number of suppliers available. The fewer the suppliers the more leverage they have. A robust and reliable supply base is very hard to develop if it is not already in place. The lack of a robust supply base would push companies into manufacturing such elements. Their original decision was to rely on external suppliers to procure its electric battery. This decision assumed that the end users would not care whether the battery was produced by them or by another company. They are also a software company and was focused on gaining a competitive edge through other means. This seemed as a solid reasoning at first, however a deeper analysis of the existing supply chain base tells a different story. There are many prominent lithium ion battery manufacturers for electric vehicles in the world. Which is why it coming as no surprise that many cars manufactures such as Nissan, Hyundai and BMW have chosen to procure their electric car

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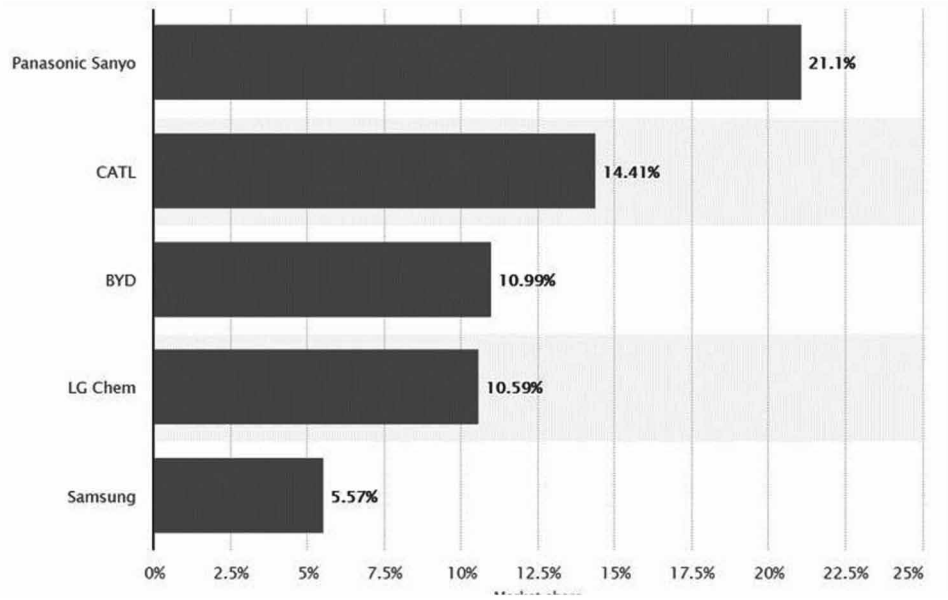
Figure 6. Battery market shares (Source: Statista.com)



batteries by buying them directly from them. However, the main difference between this company and other electric car competitors companies such as BMW, Nissan or Hyundai is that while these companies focus primarily on diesel and fuel powered cars, they are purely focused on producing electric cars. They have long suffered from problems in their supply chain and blamed unreliable contractors for failing to produce as many cars as promised. (Cendrowski, 2017).

Number of lithium ion battery suppliers available: Only a handful of lithium ion battery suppliers control a clear majority of the market share. The diagram below shows the market share of the biggest lithium ion battery suppliers. The bar chat in Figure 6 presents the lithium ion battery market share of manufactures.

Availability of viable and competent suppliers: Not only the number of lithium ion battery suppliers in the world is small, they have repeatedly proved that incapability of meeting high demand for lithium ion batteries. In 2012, a statement was made saying that the major issue that was confining them was not the demand on their products but rather by their inability to ramp up their production. Furthermore, renowned Elon Musk (the former CEO of Tesla) has made a statement that constraint on the production of electric vehicles is the cells. This provided a deep insight of their strategy to limit their reliance over the external supplier for lithium ion batteries requirement and develop their own solution for the energy demand. Author further deepened the research into why only they have faced the challenge with available suppliers by considering their reported failures. At the same time, no other electric car manufacturer has similar dissatisfaction rate from demand-supply as of them. The answer to this question lies in the numbers. Their major and only produce is electric vehicles. They don't manufacture any diesel or gasoline vehicles. On average, car manufacturers that produce electric vehicles range between 0.5% and 2% of their total sales. The second largest EV manufacturer is BMW and only 7.4% of their total sales are attributed to their EV sales. Their sales on the other hand are 100% from electric vehicles. While other car manufacturers have the luxury of moving between the EV market and the traditional car market, they

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Figure 7. Model-wise battery cell ratio

Model	Engine Power	Cells	Cells per brick	Bricks	Modules
Model 3	50 kWh	2976	31	96	4
Long Range	74 kWh	4416	46	96	4
S / X	100 kWh	8256	516	-	16

simply cannot and does not aim for. However, to remain unbeatable in the market position securing a stable source of lithium ion batteries is critical for its long-term survival.

This company, yes should be rightly identified by now – Tesla needs to ramp up its production if they want to stay competitive and stay in the market. Elon Musk has always had a 3-stage plan. The first stage was to build an electric car that would look great and prove that electric vehicles are more desirable if not more desirable than traditional cars. They produced the roadster as their first step. The next step was to produce a high-end car that would necessarily be expensive but should prove to as functional as fuel based and electric counterparts. They has achieved this part of the plan with the Model S. The third stage is ramping up production and producing less expensive yet high-end electric vehicles. This milestone encompasses challenges and regular delays as to achieve this requires open and free control over the battery production or supply which is constrained by supplier's inability. It is evident that they can't survive without a stable supply of lithium ion batteries. Imperatively, to produce their own lithium ion batteries, they made a huge and justified investment of 5-billion-dollar in the form of giga factory. Failure to secure enough lithium ion batteries will open gateways to the high risk and less predictable success of this company. Based on supply base capability, they should continue to plan, evolve and implement stable strategies for the battery production.

Architecture

Efficient battery cell but with smaller battery size is produced. Cell pertaining to world's highest energy density. From model 3's 50 kWh to their S and X's 100 kWh, the increase in the battery bricks can be observed. This high-performance cell is designed and manufactured by Tesla and Panasonic in collaboration in order to give the optimal performance with a lower manufacturing cost. Increased cells don't obviously increase the battery size, thus save the space and weight in the vehicle for other use. Figure 7 presents Model-wise Battery Cell Ratio.

They has innovated in the direction of the Cooling/heating system with an ingenious design by abandoning external battery pack heater. No matter the car is moving or parked, the battery will be heated by the heat generated from powertrain. (Young et al., 2013). A liquid cooling/heating circuit is passing through the cells, which controls the temperature of the battery and helps the vehicle to keep the good performance even in the cold weather. They have further claimed that they have reduced the use of cobalt content per battery pack while increasing nickel content and still maintaining superior thermal stability. This has not only lead to the reduced cost for manufacturing batteries since the cobalt price have more than doubled over the past year, but also the reduced gross weight for the model 3. (Lambert, 2018, May 03).

Automated high-speed charging from underneath the vehicle: Model 3 pack has no externally accessible high voltage connector other than the charge port, which terminates the idea of an autonomous charging access point under the vehicle. They have been investigating on new ways to automated high-speed charging with external cooling. With more sophistication in automation and other manufacturing

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techniques, cost effective and efficiency and continuous improvement, it is said undoubtedly that it will attract customer's attention from traditional fuel-based cars. All these success factors put a variably increasing load on battery for the performance. Thus, it is very critical for Tesla to adopt the "make" strategy given the strong technique deposit they have. This would also enable them to independently customize their solutions over relying upon other nodes in the supply chain.

FUTURE RESEARCH DIRECTIONS

There are number of major challenges that this company can possible face regarding their decision to make their own lithium ion batteries in the Gigafactory. Those may start from the exponentially increasing investment cost involved in the setting up high tech facilities, fund extensive research & development projects, training the personnel for the requirements, Uncertain market and unpredictable customer, continuous innovation entailing to loose control, reduced maintenance cost and reach toward the 100% Safety and Reliability. They might need to upgrade models and process systems frequently in order to sustain in the market.

CONCLUSION

Customer, universally, is interested in leveraged return on any investment. This company Tesla's customer, like any customer is neutral to Make or Buy Strategy. Customer is purely interested in fast delivery of vehicle, premium features and operational effectiveness as fuel counterparts are and on demand maintenance or service. Author summarized customer factor not contributing weight in make or buy analysis in order to maintain the customer's perspective, however found from analysis of automotive's trends and demand to recommended Make strategy for sufficing the customer and requirements in long run. In the case of technology, author establishes the relationship of factors in the form of equation below -

Focus toward new design and redesign + Commitment toward Battery Innovation = Outsource Body in white components only (No Core strategic product i.e. Battery).

Competition position enforces make strategy for Battery as to maintain absolute lead in technology and manufacturing position. In lieu of searching capable supplier, Production of battery is termed strategic for survival. They have a solution: Gig factory. Considerable, make strategy gives this firm an edge and flexibility over integration of their products. Figure 8 presents the summary of result.

Figure 8. Conclusion

Factor	Make	Buy
Customer Importance	Neutral	Neutral
Technology Clock-speed	✓	
Competitive position	✓	
Capable Supplier	✓	
Architecture	✓	

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Tesla' present strategy to make battery is henceforth realized beneficial through this study.

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KEY TERMS AND DEFINITIONS

Assembly Line: An assembly line is a manufacturing process in which parts are added as the semi-finished assembly moves from workstation to workstation where the parts are added in sequence until the final assembly is produced.

Battery Pack: A battery pack is a set of any number of (preferably) identical batteries or individual battery cells. They may be configured in a series, parallel or a mixture of both to deliver the desired voltage, capacity, or power density.

EV: An electric vehicle, also called an EV, uses one or more electric motors or traction motors for propulsion. An electric vehicle may be powered through a collector system by electricity from off-vehicle sources, or may be self-contained with a battery, solar panels or an electric generator to convert fuel to electricity.

Lithium-Ion Battery: Lithium batteries are primary batteries that have lithium as an anode. These types of batteries are also referred to as lithium-metal batteries. They stand apart from other batteries in their high charge density (long life) and high cost per unit. Depending on the design and chemical compounds used, lithium cells can produce voltages from 1.5 V (comparable to a zinc–carbon or alkaline battery) to about 3.7 V.

Metal Air: A metal-air electrochemical cell is an electrochemical cell that uses an anode made from pure metal and an external cathode of ambient air, typically with an aqueous or aprotic electrolyte.

Supply Chain: A supply chain is a system of organizations, people, activities, information, and resources involved in moving a product or service from supplier to customer.

Value Chain: A value chain is a set of activities that a firm operating in a specific industry performs in order to deliver a valuable product or service for the market.

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Chapter 28
Multi-Tier Supplier Selection Using Total Cost of Ownership and Data Envelopment Analysis

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ABSTRACT

Quality management across multiple tiers is vital to minimize cost of quality in global supply chains. In this chapter, the authors address the problem of supplier selection in multi-tier global supply chains with the purpose of overall quality management. A hybrid approach based on total cost of ownership (TCO) and network data envelopment analysis (DEA) is proposed. The TCO looks beyond the quoted cost to cover additional true costs related to the entire purchasing cycle. The cost categories included are quoted price, manufacturing costs, quality costs, design costs, logistics costs, after sales service, and social/environmental costs. Network DEA is used to rank the suppliers based on the TCO cost categories. The advantage of network DEA is its ability to investigate intermediate linkages between different stages of the supply chain. The results of network DEA are efficient suppliers and improvement targets for inefficient suppliers for improving overall quality in global supply chains. A numerical application is provided.

INTRODUCTION

With the complexity of today's supply chains; firms have difficulty keeping track of all the activities happening in the supply chain. Less visibility and control of key processes have become the result of manufacturing, logistics and other roles such as outsourcing (Morehouse and Cardoso, 2011). As a result, the supply chain is now more vulnerable to frauds than before. Due to poor traceability of supplier quality across multiple tiers in global supply chains, several serious incidents have occurred in recent years. Babies got poisoned by contaminated milk in China (Bradley, 2008) due to use of melamine instead of protein nitrogen by one supplier to gain some extra profit. In 2007, Canadian pet food manufacturer and retailer, Menu Food, had a massive recall of one popular pet food product because it caused sickness and death of animals due to presence of high melamine level in some ingredients imported from Chinese

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suppliers (Chen *et al.,* 2014). Mattel recalled millions of toys in 2007 due to the use of contaminated paint containing high levels of lead content which is harmful for children health (Viswanadham and Samvedi, 2013).

To minimize the occurrence of such incidents, firms have strived to achieve successful supply chain collaboration. Collaboration can improve the traceability and visibility among the supply chain (Sarpong, 2014), which in turn improves the quality of the final product or service. Moreover, collaboration can deliver significant benefits to all parties such as excess inventory reduction, bullwhip avoidance, business synergy enhancement, flexibility and increase joint innovation (Cao and Zhang, 2011). Supply chain performance enhancement (Vereecke and Muylle, 2006) by leveraging the knowledge and resources of suppliers (Cao and Zhang, 2011) are some results of a successful collaboration.

Although product design, warehousing, and distributions centers can all be the subject of quality improvement programs; purchasing emerges on top in the list being the biggest contributor to the cost of quality. Effective purchasing decisions are necessary to achieve an acceptable level of cost and quality trade-off and gain overall efficiency in the supply chain. Supplier evaluation process is very critical to purchasing management and therefore essential for the success of the focal firm (Choi and Hartley, 1996; Singh, 2014). It is a complex multiple criteria decision making problem that requires careful selection of criteria (Omurca, 2013). Both qualitative and quantitative criteria should be used in evaluating the supplier performance. Additionally, it should speak the language of business, or money, to ensure acceptance among purchasing managers. It must also reflect the network structure of the supply chain. As a result, all the *n*-tier suppliers and the linkages between them should be evaluated for overall quality management in supply chains. We argue that evaluation of suppliers is only the first step towards a successful collaboration relationship. Evaluation will reveal the weak areas of each supplier and recommend methods for improvement. Moreover, this evaluation will be the basis for supplier development programs.

In this paper, we are addressing the problem of supplier selection in multi-tier global supply chains with the purpose of overall quality management. A hybrid approach based on total cost of ownership (TCO) and network data envelopment analysis (DEA) is proposed. The strength of TCO is that it looks beyond the quoted cost to cover additional true costs related to the entire purchasing cycle. In addition to the quoted price, it includes order placement costs, research costs, transportation costs, receiving costs, inspection costs, holding costs, and disposal costs (Bhutta and Huq, 2002). DEA is a powerful linear programming based technique to measure the relative performance of decision making units (DMUs) with multiple inputs and multiple outputs. It can handle both quantitative and qualitative input/output data. DEA does not require the decision maker to assign weights to each indicator but calculates weights from the given data. Additionally, DEA finds the efficient decision making units (suppliers) and provides improvement targets for inefficient suppliers to become efficient.

The rest of the paper is organized as follows. In section 2, we present the literature review. Sections 3 and 4 contain the proposed solution approach and its numerical application. The conclusions and future works complete the paper in section 5.

LITERATURE REVIEW

In today's world it is not possible for a single organization to own its entire supply chain like the Ford Company in the first half of the 20th century (Gelderman, 1989). To stay competitive in global market; organizations have to outsource many critical business processes and value chain activities to suppli-

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ers thousands of miles away to reduce cost or increase responsiveness (Nieminen and Takala, 2006). Therefore, the supply chain has become more and more complex. Especially, when the direct supplier (first tier) outsources part of its business to another supplier.

With globalization, organizations face several challenges in managing supply chain quality (Jain and Benyoucef, 2008; Kuei *et al.*, 2011; Morehouse and Cardoso, 2011; Tse and Tan, 2011; Klassen and Vereecke, 2012; Tachizawa and Wong, 2014). To name a few are less visibility and control of key processes, environmental protection, social issues, inventory reduction, and adoption of advanced technologies such as enterprise resource planning (ERP), customer relationship management (CRM), and product lifecycle management (PLM). Therefore, firms are striving to achieve successful supply chain collaboration to limit some of these impacts. Collaboration can improve the traceability and visibility among the supply chain members (Sarpong, 2014), which in turn improves the quality of the final product or service. The first step in collaboration is partner selection which starts with supplier evaluation in buyer-supplier partnerships.

Supplier Evaluation

Supplier evaluation is a multi-criteria decision making problem that involves several qualitative and quantitative factors. Several studies have been conducted to develop decision-making models that can address this problem effectively (Zeydan *et al.*, 2011). Ghodsypour and O'Brien (1998) classify supplier evaluation models into two groups: single objective models and multiple objective models. Single objective models use one criterion, such as the cost, as an objective function and other criteria as constraints. This approach has two weaknesses: it considers all constraints equally which rarely happens in reality, and it faces significant difficulties when considering qualitative factors. Moreover, it is very risky to rely on a single criterion when evaluating a supplier. Therefore, using a multi-criteria approach is preferable over the single criterion approach (Zeydan *et al.*, 2011).

One of the earliest contributions to supplier evaluation and selection criteria was of Dickson (1966). In his study he identified 23 criteria for supplier evaluation and reported quality, delivery and performance history are the most important criteria. Erdem and Gocen (2012) listed 60 criteria for supplier evaluation among which price, quality, availability and delivery are the most significant ones. These results confirm the multi-criteria nature of supplier evaluation problem.

Ho *et al.* (2010) and Erdem and Gocen (2012) classify supplier evaluation and selection approaches into linear weighting models (e.g. analytic hierarchy process, interpretative structure modeling, fuzzy set theory, and total cost of ownership), mathematical programming models (e.g. data envelopment analysis, linear programming, mix integer programming, and goal programming), and artificial intelligence/statistical/probabilistic models (e.g. case based reasoning, genetic algorithm, neural network, and expert systems). Table 1 presents a summary of commonly used approaches for supplier selection.

Global (Multi-Tier) Supplier Evaluation

Supplier evaluation should be extended beyond the first-tier suppliers to cover all suppliers across the supply chain. Many researches consider this as one way to manage the supply chain (Rao, 2002; Zhu and Sarkis, 2004; Andersen and Skjoett-Larsen, 2009; Mueller *et al.*, 2009; Zhu *et al*., 2012, Noshad and Awasthi 2015). For global supplier evaluation, multicriteria decision making approaches have been predominantly used. Min (1994) proposed a multi-attribute utility approach for international supplier se-

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Table 1. Summary of popular supplier evaluation techniques

Technique	Description	Benefits	Drawbacks	Supplier evaluation in literature
Total Cost of Ownership (TCO)	A purchasing tool which is aimed at understanding the real cost associated with the entire purchasing cycle	• Cost transparency • Improves supplier evaluation and selection process • Defines the supplier performance expectations • Helps prioritising supplier performance areas • Cost savings opportunities • Better understanding of supplier performance and cost structure • Can be the basis for supplier negotiations • Helps building strategic collaboration efforts.	• Complex approach as it may require methods to quantifying non-monetary costs • Lack of an accounting and costing system • Requires culture change • No standard model	Ellram (1993);Degraeve and Roodhooft (1999);Dogan and Aydin (2011);Bhutta and Huq (2002)
Analytic Hierarchy Process (AHP)	A mathematical model that allows complex problems to be represented in a hierarchical form.	• Flexibility • Simplicity • Can incorporate quantitative and qualitative criteria	• Very complex pairwise comparisons in case of many alternatives and criteria. • Artificial limitation of the 9-point scale.	Akarte *et al.* (2001); Muralidharan *et al.* (2002); Chan (2003); Liu and Hai (2005); Hou and Su (2007); Bruno *et al.* (2012); Deng *et al.* (2014)
Goal Programming (GP)	A multi-objective decision making technique that involves a set of goals that may contradict with each other.	• Helps when we have multiple goals that are conflicting and not all achievable. • Allows ranking of goals so that the lower priority goals are considered only when higher priority goals are fully satisfied • Can be used when satisfactory solution is required rather than an optimized solution	• Can be costly and time consuming • The generated solution is satisfactory rather than an optimum one	Karpak *et al*. (2001); Çebi and Bayraktar (2003);Wang *et al*. (2004); Perçin (2006); Kull and Talluri (2008); Mendoza *et al*. (2008); Osman and Demirli (2010); Erdem and Gocen (2012)
Data Envelopment Analysis (DEA)	A linear programming based technique to measure the efficiency of a set of entities that have multiple inputs and outputs.	• Non-parametric analysis technique • Considers both quantitative and qualitative data • Finds the efficient supplier as well as the amount and source of inefficiency of inefficient suppliers • Provides improvement targets	• May draw confusion when defining the input and output criteria • Subjective assignment of qualitative criteria • Can mislead the purchase manager, as efficient supplier may not be an effective one.	Braglia and Petroni (2000); Liu *et al.* (2000); Forker and Mendez (2001); Narasimhan *et al.* (2001); Talluri and Baker (2002); Talluri and Sarkis (2002); Talluri and Narasimhan (2004); Garfamy (2006); Ross *et al.* (2006); Saen (2006); Seydel (2006)

lection. Chan and Kumar (2007) studied global supplier development considering risk factors using fuzzy extended AHP-based approach. Wadhwa (2008) proposed a multi-objective decision support system for global supplier selection based on analytic hierarchical process (AHP) and total cost of ownership. Chan et al (2008) proposed a fuzzy-AHP approach for global supplier selection. Ku et al. (2010) performed global supplier selection using fuzzy analytic hierarchy process and fuzzy goal programming. Kumar et al. (2011) proposed global supplier selection process for food packaging using total cost of ownership model and weighted qualitative criteria matrix. Tektas and Aytekin (2011) performed supplier selection

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in the international environment using AHP and linear programming for Turkish and Australian companies. Hammami et al. (2011) proposed optimization models for supplier selection in global context. Tas (2012) proposed a fuzzy AHP approach for selecting global supplier in pharmaceutical industry. Shaw et al. (2013) proposed an AHP multi-objective fuzzy linear programming approach for global supplier selection considering sustainability and carbon footprint. Viswanadham (2013) performed multi-tier supplier selection for a sustainable global supply chain using grey relational analysis approach. Chen et al. (2014) applied goal programming for resilient global supplier selection in automotive sector. Zhang et al. (2015) proposed a fuzzy extended analytic network process-based approach for global supplier selection. Gold and Awasthi (2015) performed sustainable global supplier selection considering sustainability risks from (1+n)th tier suppliers using fuzzy AHP based approach. Deepika and Kannan (2016) perform global supplier selection using intuitionistic fuzzy analytic hierarchy process.

SOLUTION APPROACH

The proposed approach comprises of two main steps. The first step involves finding the true cost associated to each supplier using Total Cost of Ownership (TCO). The second step involves evaluating performance of *n*-tier suppliers based on the identified costs using network data envelopment analysis (DEA). The strength of the proposed work lies in the use of TCO and network DEA which not only aids in ranking suppliers but also helps identify weak points in the supplier performance and suggests improvement targets. The two steps are explained in detail as follows.

Total Cost of Ownership

The total cost of ownership (TCO) concept was first proposed by an IT research and advisory company called Gartner in 1987 to compute the total costs of owning and managing IT infrastructure in a company (Bremen *et al.*, 2007). Later, the concept has been used to calculate total cost of purchased goods in general (Ellram, 1993). TCO is a purchasing tool and a philosophy aimed at understanding the real cost of buying a particular good or service from a supplier (Ellram, 1995). It is a complex approach that requires firms to determine the associated costs and find ways to quantify non-monetary costs to better understand and manage costs. In addition to the quoted price, TCO also considers order placement costs, research costs, transportation costs, receiving costs, inspection costs, holding costs, and disposal costs (Bhutta and Huq, 2002).

Ellram (1993) suggested a more general approach for TCO based on the order of occurrence: pre-transaction costs, transaction costs, post-transaction costs. Pre-transaction costs involve all costs related to activities that occur prior to order placement such as identifying requirements, searching for a supplier, negotiation, and supplier evaluation. Transaction costs occur at the time of purchasing and receiving the ordered item. Price, delivery charges, and inspection are some examples of transaction costs. Post-transaction costs occur after closing the order. In other words, post-transaction costs include all activities that happen after the organization owns the ordered item such as maintenance costs and quality failures costs. Maltz and Ellram (1997) used the categories as management, quality, delivery, service, communications, and price. Degraeve *et al*. (2005) present a matrix model consisting of supplier level, product level, order level, and unit level activities and their associated life cycle costs. Dogan and Aydin (2011) proposed an integrated model based on total cost of ownership and Bayesian networks to efficiently

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select a supplier using product design cost, downtime cost, logistics cost, operation cost, quality related cost, administrative cost, and transaction cost as the cost categories.

Researchers have presented different costs categories to serve different purposes but no study so far, according to our knowledge, has suggested cost categories from collaboration perspective. Our goal is to fulfill this gap by incorporating collaboration into our selection of the cost categories. Direct and indirect costs are broken down into 6 categories. These TCO costs can be considered as a guide depending on the industry or service type. Table 2 details these cost categories. The total cost of ownership of each supplier is calculated as the quoted price plus the associated costs.

Network DEA

To evaluate the performance of suppliers using the total costs of ownership (Table 2), network DEA is used. The major drawback of traditional DEA is that it treats DMUs as a "black box" by considering only the initial inputs and the final outputs and omits the actual activities happening inside (Lewis and Sexton, 2004; Kao, 2009; Zhu, 2009; Azbari *et al.,* 2014; Yang *et al.,* 2014). The traditional DEA can be used for selecting efficient supplier among potential suppliers for a new product but its use is limited in evaluation of upstream suppliers, as it ignores the sub-suppliers and their inter-linkages. In such cases, network DEA is preferable over the traditional DEA especially due to its ability to detect efficiencies missed by the traditional DEA. In network DEA, the intermediate linkages are the outputs of the previous stages and inputs to the next (subsequent) stages.

Our network DEA model is based upon Zhu (2009) which embodies the structure of the supply chain to define and evaluate efficiency of the supply chain and its individual members. Moreover, the model yields a list of optimal values for all members that establish an efficient supply chain. The difference of our work with Zhu (2009) lies in the use of different cost categories identified using TCO approach in Table 2.

Suppose we have *n* tier suppliers under evaluation (*n* DMUs). For each supplier we have *J* observations and a different set of inputs and outputs. If these inputs and outputs are associated with a specific member of the supply chain, we call them "direct" inputs and direct outputs (Zhu, 2009). We refer to them as DI^{Δ} and DO^{Δ}, where, DI^{Δ} represents the direct inputs and DO^{Δ} represents the direct outputs for a supply chain member Δ. There are also "intermediate" inputs and outputs between two supply chain members, where usually the outputs from one member become inputs to other member. Calculation of the intermediate measures should be done through coordination among the members of the supply chain (Parlar and Weng, 1997;Thomas and Griffin, 1996). For example, one member would like to maximize the price while the other may prefer to minimize the cost. Figure 1 presents the graphical illustration of a 3 tier network comprising of sub-sub-supplier, sub-supplier, and supplier linked through common inputs and outputs.

In this setting, overall supply chain efficiency can be measured using the following network DEA model:

$$\Omega^{*} = \min \frac{\sum_{i=1}^{n} w_i \Omega_i}{\sum_{i=1}^{n} w_i}$$

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Table 2. TCO costs' categories

TCO Categories	TCO Sub Categories	Author	Global Context	Measurement Method	Product Vs. Service	Input/ Output
Manufacturing Costs	Raw Material	Bhutta and Huq (2002)	Yes	Quantitative costs	P	I
	Labour		Yes	Quantitative costs	P	I
	Machine depreciation		Yes	Quantitative costs	P	I
Quality Costs	Quality Audit Cost	Song *et al.* (2007)	Yes	Qualitative cost: Inspection cost and validation cost: Standard cost per hour x time spent	P,S	I
	Rework Cost	Song *et al.* (2007)	Yes	Rework cost per unit x number of units reworked	P	I
	Quality Confirmation	Hurkens *et al.* (2006)	Yes	Qualitative cost: Labor cost of quality confirmation: No. of assigned people x Labor cost x Percentage of labor spent on quality confirmation. Quality confirmation cost per supplier: No. of checks required to accept a new item x Labor cost of quality confirmation.	P,S	I
Design Costs	Technological capability	Dogan (2011)	Yes	Qualitative cost: He propose an assumption that the design cost will decrease if the supplier is technologically capable, flexible and financially healthy supplier	P	I
	Flexibility		Yes		P	I
	Financial Factors		Yes		P	I
Logistics Costs	Freight	Dogan (2011)	Yes	Quantitative costs	P	I
	Handling and packaging		Yes	Quantitative costs	P	I
	Tariffs, duties and Import fees		Yes	Quantitative costs	P	I
	Customer Service		Yes	Quantitative costs	P	I
	Outbound costs		Yes	Quantitative costs	P	I
	Tariffs warehousing		Yes	Quantitative costs	P	I
After sale service	Service Cost	Bhutta and Huq (2002)	Yes	Quantitative costs	P	I
Social / Environmental Costs	Energy Cost	None	Yes	Quantitative costs	P	I
	Water Cost	None	Yes	Quantitative costs	P	I
	Social Policies	None	Yes	Inspection Cost: No. of assigned people x Labor cost x Percentage of labor spent on inspection.	P,S	I
	Fines and Penalties	None	Yes	Quantitative cost	P	I
Price	Price	Bhutta and Huq (2002)	Yes	Quantitative costs	P,S	I

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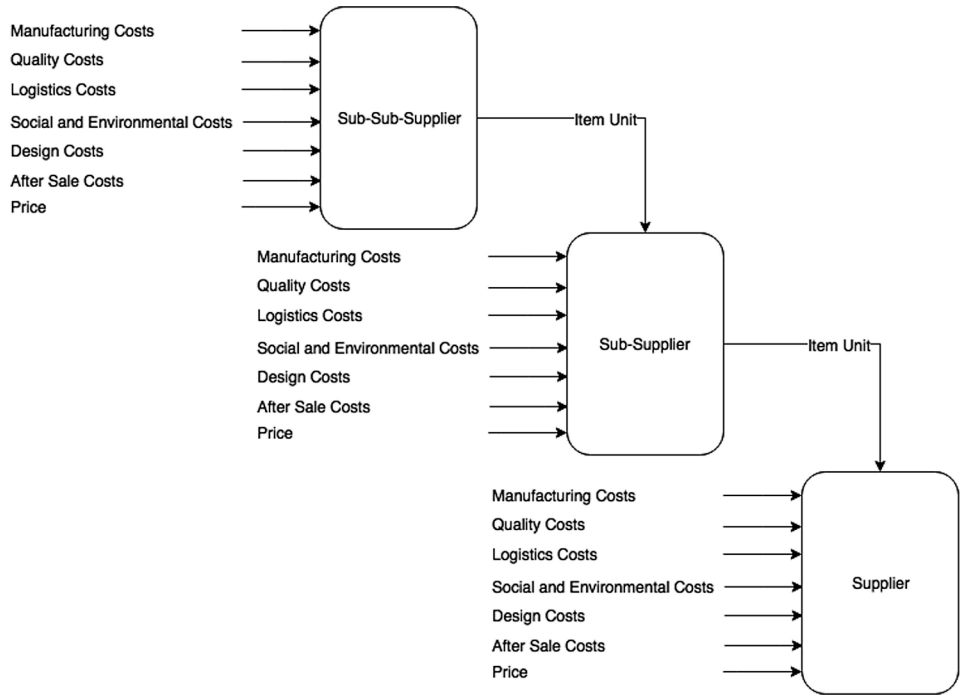
Figure 1. Example of 3-tier suppliers



subject to

(Sub – Sub Supplier S_1)

$$\sum_{j=1}^{J} \lambda_j x_{ij}^{S_1} \leq \Omega_1 x_{ij_0}^{S_1}, \quad i \in DI^{S_1}$$

$$\sum_{j=1}^{J} \lambda_j y_{rj}^{S_1} \geq y_{rj_0}^{S_1}, \quad r \in DO^{S_1}$$

$$\sum_{j=1}^{J} \lambda_j z_{tj}^{S_1 - S_2} \geq z_{tj_0}^{S_1 - S_2}, \quad t = 1, \ldots, T .$$

$\lambda_j \geq 0, j=1,..,J$

(Sub Supplier S_2)

$$i \in DI^{S_2}$$

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$$\sum_{j=1}^{J}\beta_j y_{rj}^{S_2} \geq y_{rj_0}^{S_2}, \quad r \in DO^{S_2}$$

$$\sum_{j=1}^{J}\beta_j z_{tj}^{S_1-S_2} \leq z_{tj_0}^{S_1-S_2}, \quad t = 1,\ldots,T$$

$$\sum_{j=1}^{J}\beta_j z_{mj}^{S_2-S_3} \geq z_{mj_0}^{S_2-S_3}, \quad m = 1,\ldots,M$$

$\beta_j \geq 0, j=1,\ldots,J$

(Supplier S_3)

$$\sum_{j=1}^{J}\delta_j x_{ij}^{S_3} \leq \Omega_3 x_{ij_0}^{S_3}, \quad i \in DI^{S_3}$$

$$\sum_{j=1}^{J}\delta_j y_{rj}^{S_3} \geq y_{rj_0}^{S_3}, \quad r \in DO^{S_3}$$

$$\sum_{j=1}^{J}\delta_j z_{mj}^{S_2-S_3} \leq z_{mj_0}^{S_2-S_3}, \quad m = 1,\ldots,M$$

$\delta_j \geq 0, j=1,\ldots,J$

where:

Ω_i is efficiency score of supplier$_i$.
Ω^* is the optimum efficiency of the supply chain, can be viewed as the supply chain best practice when it's equal to 1

w_i is a user specific weight preference assigned to reflect the preference over each supplier. The weights w_i represent the relative importance or contribution of different stage suppliers to the overall efficiency of supply chain. One reasonable choice for the weights is the proportion of the supply chain's total input resources used by the stage supplier and it indicates the relative size of the supplier (Cook et al. 2010).

λ_j is the j^{th} observation computed weights of the sub-sub-supplier.
β_j is the j^{th} observation computed weights of the sub-supplier.
δ_j is the j^{th} observation computed weights of the supplier.
x_{ij}^{Δ} is the consumed amount of input i by supplier Δ in the j^{th}. observation.

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y_{rj}^{Δ} . is the produced amount of output *r* by supplier Δ. in the j^{th}. observation.
$z_{tj}^{S_1-S_2}$. is the t^{th}. intermediate output from sub-sub-supplier S_1. to sub-supplier S_2. in the j^{th}. observation.
$z_{mj}^{S_2-S_3}$. is the m^{th}. intermediate output from sub-supplier S_2. to supplier S_3. in the j^{th}. observation.

Additional constraints can be added. For example, if we have intermediate outputs that go from supplier S_3. to sub-supplier S_2., then we have

$$\sum_{j=1}^{J} \delta_j z_{gj}^{S_3-S_2} \geq z_{gj_0}^{S_3-S_2}, \quad g = 1,\ldots,G\,.$$

Bhe model tries to find the efficiency of each supplier by comparing each input or output with different observations of that input or output. Supply chain efficiency Ω^*. is equal to 1 practice values of inputs and outputs) when the efficiencies of all suppliers equal 1.

NUMERICAL APPLICATION

To illustrate the application of proposed approach for multi-tier supplier evaluation, let's consider the 3-tier supply chain network demonstrated in Figure 1. There are three levels of suppliers namely sub-sub supplier, sub-supplier, and supplier. Each supplier's ultimate output is the part that he supplies to the next tier's supplier. We are assuming that the suppliers belong to the same geographical location, supplying similar type of products.

Input Data

The inputs (TCO cost categories) and outputs (item units) of each supplier are computed at random between the ranges shown in Table 3.

The resulting input data is presented in Table 4. Ten observations were generated and network DEA was applied.

Table 3. Input data ranges

Cost Category	Sub-sub supplier	Sub supplier	Supplier
Manufacturing Costs	50-130	70-200	200-370
Quality Costs	20-40	20-40	30-65
Logistics Costs	70-170	90-180	200-340
Social and Environmental costs	30-80	50-120	100-160
Design Costs	50-70	60-99	100- 160
After Sale Costs	20-50	20-50	30-60
Price	10 -220	300-400	600-780

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Table 4. Hypothetical data generated using Excel random routine

		TCO Categories	Observation									
			1	2	3	4	5	6	7	8	9	10
Sub Sub Supplier	Input	Manufacturing Costs	78	70	93	90	73	102	104	123	80	81
		Quality	22	26	32	30	28	29	38	38	24	34
		Logistics	116	131	143	101	98	146	105	166	169	154
		Social and Environmental	79	57	50	48	70	62	69	58	58	48
		Design Costs	50	57	60	60	70	52	67	57	67	59
		After Sale	49	40	46	39	33	38	46	45	34	37
		Price	107	172	158	150	148	120	128	166	169	126
	Output-Input	Item Unit	1	1	1	1	1	1	1	1	1	1
Sub Supplier	Input	Manufacturing Costs	72	60	104	139	110	106	182	145	143	174
		Quality	29	30	24	30	20	28	32	26	30	26
		Logistics	109	170	161	155	142	142	175	172	174	146
		Social and Environmental	95	70	99	75	87	98	103	108	106	97
		Design Costs	73	61	75	84	81	86	99	85	90	96
		After Sale	39	37	41	42	34	29	41	30	40	40
		Price	347	355	333	341	348	359	360	368	374	367
	Output-Input	Item Unit	1	1	1	1	1	1	1	1	1	1
Supplier	Input	Manufacturing Costs	288	261	309	230	309	263	284	327	297	313
		Quality	45	38	40	42	48	52	52	54	52	63
		Logistics	270	284	276	271	268	299	251	232	301	315
		Social and Environmental	140	126	136	138	144	149	146	142	150	159
		Design Costs	127	110	138	134	138	132	149	140	141	140
		After Sale	46	35	43	36	40	40	45	45	45	50
		Price	700	638	658	649	651	668	745	676	734	710
	Output	Item Unit	1	1	1	1	1	1	1	1	1	1

Model Results

The efficiency scores for the three suppliers are presented in Table 5. The efficiency score of the supply chain is denoted by Ω^{*}., sub-sub supplier by Ω_{1}., sub-supplier by Ω_{2}. and supplier by Ω_{3}. respectively. It can be seen from Table 5 that although a number of observations are efficient but only observations 2 and 4 are indicating a supply chain efficient score (=1), which can be considered as supply chain best practices and used for supplier improvement program. Furthermore, in the first observation only Ω_{3}. is inefficient with efficiency score of 0.979, which means this supplier should use 97.9% of his resources to become 100% efficient. Similarly, in observations 5 and 6 we notice that Ω_{3}. is 99.8% and 96% efficient respectively.

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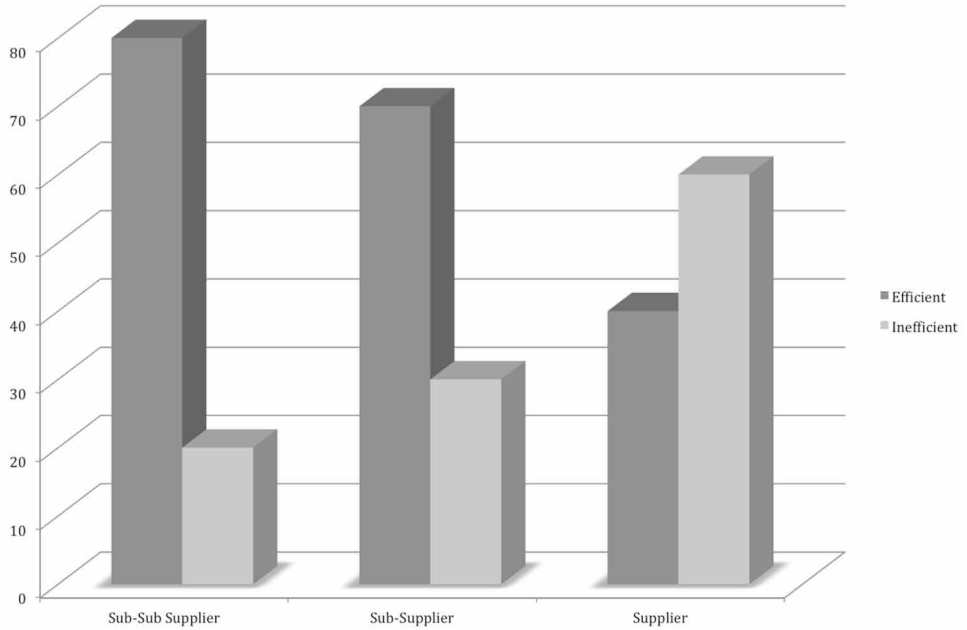
Table 5. Suppliers efficiency scores

Observation	Supply Chain Efficiency			
	Ω^*.	Ω_1.	Ω_2.	Ω_3
	0.993	1	1	0.979
2	1	1	1	1
3	0.994	0.983	1	1
4	1	1	1	1
5	0.999	1	1	0.998
6	0.987	1	1	0.960
7	0.978	1	0.940	0.995
8	0.988	0.965	1	1
9	0.935	1	0.915	0.891
10	0.946	1	0.938	0.899

Figure 2 presents the efficiency scores for the three suppliers. It can be observed that the sub-sub sr was efficient in 80% of the observations while the sub-supplier was efficient in 70% of the observations. On the other hand, the supplier was efficient in 40% of the observations only.

Table 6 reports the input targets that all suppliers should follow to improve their performance. It can be the basis for a supplier development program that aims toward improving the supply chain performance. For example Ω_3 in the first observation should decrease manufacturing cost to 281.9 from 288, quality from 45 to 44.05, logistics cost from 270 to 264.28, Social and Environmental costs from 140 to

Figure 2. Efficiencies of the three suppliers



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137.04, technology cost from 127 to 124.31, after sales cost from 46 to 45.03, and finally decrease the quoted price to be 685.18. As a result, Ω_3 will be efficient for this observation.

Recommendations

Based on our findings, following recommendations are generated:

1. The main supplier should join a supplier development program being efficient in only 40% of the observations.
2. Observations 2 and 4 are considered best practices. Therefore, any supplier development program should consider these values.
3. Collaboration is considered an added value only when TCO is between $1492 to $1500 for the supplier, $783 to $866 for the sub supplier, and $518 to $553 for the sub-sub supplier. These values are the results of totalling the TCO categories for each supplier in observations 2 and 4.
4. Table 6 is the basis to improve the performance of suppliers in any observation. It can be the basis for negotiation with suppliers.

Table 6. Input targets

	TCO Categories	Observation									
		1	2	3	4	5	6	7	8	9	10
Sub Sub Supplier	Manufacturing Costs	78	70	91.40	90	73	102	104	118.71	80	81
	Quality	22	26	31.45	30	28	29	38	36.67	24	34
	Logistics	116	131	140.54	101	98	146	105	160.21	169	154
	Social and Environmental	79	57	49.14	48	70	62	69	55.98	58	48
	Design Costs	50	57	58.97	60	70	52	67	55.01	67	59
	After Sale	49	40	45.21	39	33	38	46	43.43	34	37
	Price	107	172	155.28	150	148	120	128	160.21	169	126
Sub Supplier	Manufacturing Costs	72	60	104	139	110	106	171.03	145	130.91	163.16
	Quality	29	30	24	30	20	28	30.07	26	27.46	24.38
	Logistics	109	170	161	155	142	142	164.45	172	159.29	136.91
	Social and Environmental	95	70	99	75	87	98	96.79	108	97.04	90.96
	Design Costs	73	61	75	84	81	86	93.03	85	82.39	90.02
	After Sale	39	37	41	42	34	29	38.53	30	36.62	37.51
	Price	347	355	333	341	348	359	338.30	368	342.39	344.14
Supplier	Manufacturing Costs	281.90	261	309	230	308.52	252.39	282.67	327	264.61	281.49
	Quality	44.05	38	40	42	47.93	49.90	51.76	54	46.33	56.66
	Logistics	264.28	284	276	271	267.59	286.94	249.82	232	268.18	283.29
	Social and Environmental	137.04	126	136	138	143.78	142.99	145.32	142	133.64	142.99
	Design Costs	124.31	110	138	134	137.79	126.68	148.30	140	125.62	125.91
	After Sale	45.03	35	43	36	39.94	38.39	44.79	45	40.09	44.97
	Price	685.18	638	658	649	649.99	641.05	741.51	676	653.96	638.52

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Sensitivity Analysis

To study the sensitivity of our modeling framework to changes in input parameters, we removed one input at a time and then re-evaluated Ω_1, Ω_2 and Ω_3 to check if they still preserve their efficiency. Four scenarios were generated. The first scenario performs supplier selection without considering manufacturing and technology costs. The second scenario ignores quality costs and price. In the third scenario, logistics and after sales costs are eliminated. The fourth scenario ignores social and environmental costs.

First Scenario: Evaluate without manufacturing and technology costs

Table 7 shows the efficiencies without manufacturing cost. It can be seen that there is no change in efficiencies for the efficient units. Moreover the supply chain best practices are still observations 2 and 4. The same results are observed from Table 8 when technology cost is removed.

Table 7. Efficiency scores without manufacturing cost

Observation	Ω^*	Ω_1	Ω_2	Ω_3
1	0.993	1	1	0.979
2	1	1	1	1
3	0.994	0.983	1	1
4	1	1	1	1
5	0.999	1	1	0.998
6	0.985	1	1	0.955
7	0.970	1	0.940	0.970
8	0.988	0.965	1	1
9	0.934	1	0.915	0.886
10	0.946	1	0.938	0.899

Table 8. Efficiency scores without technology cost

Observation	Ω^*	Ω_1	Ω_2	Ω_3
1	0.993	1	1	0.978
2	1	1	1	1
3	0.987	0.960	1	1
4	1	1	1	1
5	0.999	1	1	0.998
6	0.987	1	1	0.960
7	0.978	1	0.940	0.995
8	0.946	0.837	1	1
9	0.935	1	0.915	0.891
10	0.946	1	0.938	0.899

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Second Scenario: Evaluate without quality costs and price

Tables 9-10 demonstrate the efficiency scores when quality costs and price are dropped respectively. Supply chain best practice is still obtained from observations 2 and 4 for both inputs. However, Ω_2 becomes inefficient in observation 8 when quality cost is removed. Likewise, Ω_1. becomes inefficient in observation 7.

Third Scenario: Evaluate without logistics and after sale costs

On the other hand, when efficiency scores are calculated without logistics cost, Ω_1. and Ω_3. lose their efficient scores in observations 7 and 8 respectively as seen in Table 11. Similarly, Ω_2 becomes inefficient in observations 6 and 8 (Table 12) when after sales cost is dropped. Supply chain best practice is still found in observations 2 and 4.

Table 9. Efficiency scores without quality cost

Observation	Ω^*	Ω_1	Ω_2	Ω_3
1	0.992	1	1	0.976
2	1	1	1	1
3	0.988	0.979	1	0.984
4	1	1	1	1
5	0.999	1	1	0.998
6	0.987	1	1	0.960
7	0.978	1	0.940	0.995
8	0.984	0.965	0.988	1
9	0.935	1	0.915	0.891
10	0.946	1	0.938	0.899

Table 10. Efficiency scores without price

Observation	Ω^*	Ω_1	Ω_2	Ω_3
1	0.993	1	1	0.979
2	1	1	1	1
3	0.989	0.983	0.984	1
4	1	1	1	1
5	0.990	1	1	0.969
6	0.977	1	1	0.930
7	0.926	0.951	0.831	0.995
8	0.988	0.965	1	1
9	0.913	1	0.847	0.891
10	0.924	1	0.911	0.860

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Table 11. Efficiency scores without logistics cost

Observation	Ω^*	Ω_1	Ω_2	Ω_3
1	0.970	1	1	0.911
2	1	1	1	1
3	0.984	0.983	1	0.970
4	1	1	1	1
5	0.993	1	1	0.980
6	0.987	1	1	0.960
7	0.914	0.915	0.940	0.887
8	0.970	0.965	1	0.944
9	0.929	1	0.915	0.870
10	0.943	1	0.932	0.899

Table 12. Efficiency scores without after sale cost

Observation	Ω^*	Ω_1	Ω_2	Ω_3
1	0.993	1	1	0.979
2	1	1	1	1
3	0.994	0.983	1	1
4	1	1	1	1
5	0.999	1	1	0.998
6	0.970	1	0.952	0.960
7	0.974	1	0.928	0.995
8	0.959	0.965	0.911	1
9	0.929	1	0.897	0.891
10	0.946	1	0.937	0.899

4th Scenario: Evaluate without social and environmental costs

Finally, different results are obtained on removing social and environmental costs. Observation 4 is no more the supply chain best practice as Ω_2 becomes inefficient (Table 13).

From the above scenarios, we found that removing or omitting some inputs affects the efficiency scores of one or more observations. These results can be summarized below:

1. Removing manufacturing and technology costs does not affect the efficiency score of any observation.
2. Dropping quality costs and price affects the efficiency of sub supplier and sub-sub supplier respectively in one observation only.
3. Evaluating without logistics costs causes sub-sub supplier and supplier to lose their efficiency score in one observation only.

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Table 13. Efficiency scores without social and environmental costs

Observation	Ω^*	Ω_1	Ω_2	Ω_3
1	0.993	1	1	0.979
2	1	1	1	1
3	0.967	0.901	1	1
4	0.994	1	0.983	1
5	0.999	1	1	0.998
6	0.987	1	1	0.960
7	0.978	1	0.940	0.995
8	0.968	0.904	1	1
9	0.935	1	0.915	0.890
10	0.945	1	0.936	0.899

4. Evaluating without after sales costs can cause sub supplier to become inefficient in two observations, which could be an indication of the importance of this input.
5. Removing the social and environmental costs caused the greatest change in the efficiency score. It caused the sub supplier to become inefficient in the best practice observation. This is an indication of the importance of this input for the DEA model.

Results Validation

For results validation, we will compare our findings with those of Tajbakhsh and Hassini (2014) and Mirhedayatian *et al*. (2014). Tajbakhsh and Hassini (2014) developed a network DEA model to evaluate the sustainability of the supply chain partners. Their work was based on the envelopment model of CCR-DEA (Cooper *et al.*, 2007). Mirhedayatian *et al*. (2014) model is based on a fuzzy structure and non-radial objective function (Tajbakhsh and Hassini, 2014). Our network model is based on Zhu (2009). To compare the performance of the three models, case study from Mirhedayatian *et al.* (2014) will be used. The case study consists of data collected from 10 Iranian beverage corporations in a supply chain of four partners: a supplier, a manufacturer, a distributor, and a retailer. Figure 3 demonstrates the supply chain network and shows the inputs and outputs of each partner and the intermediate linkages. We are using the same notations of Tajbakhsh and Hassini (2014).

Table 14 provides the description of each notation.

The data of the Iranian beverage case study is displayed in Table 15. We assume the same weight preference that Mirhedayatian *et al*. (2014) assign to each partner: w_{sup}=0.3, w_{man}=0.4, w_{dist}=0.2, and w_{ret}=0.

Table 16 shows the proposed model results for the Iranian beverage case. We notice that among the three models, DMU_1 is the most efficient. Furthermore, we notice that our model results are in agreement with Tajbakhsh and Hassini (2014) for DMU_1., DMU_2, DMU_4, and DMU_{10} which represents 40% of the cases. Moreover, DMU_1, DMU_2, DMU_4, DMU_5., DMU_8, DMU_9. and DMU_{10}. have the same rank in both models. The supplier in both models is efficient in four DMUs and the retailer is efficient in two DMUs. On the other hand, we notice tt the distributor wfficient in three DMUs of our model while it was efficient in six DMUs of Tajbakhsh and Hsini (2014). On comparing with Mirhedayatian *et al*.

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Figure 3. The supply chain of the Iranian beverage corporations' case

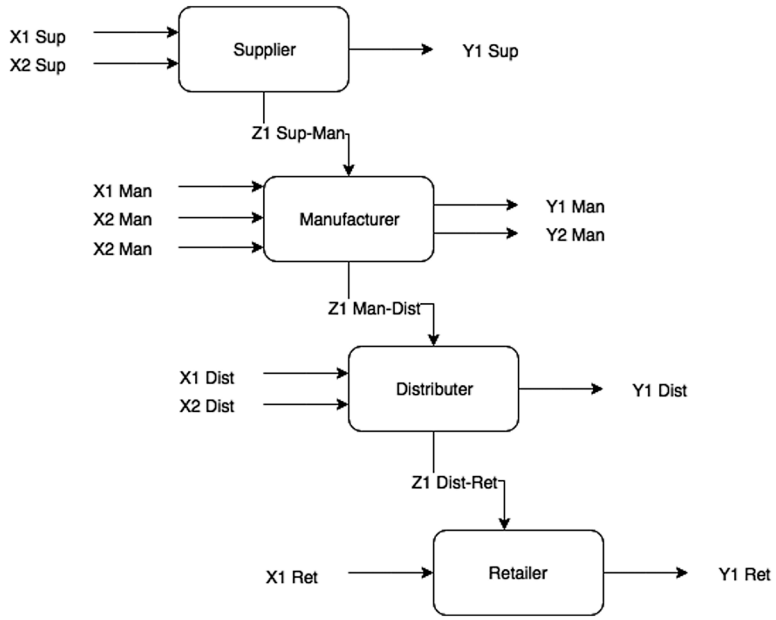

Table 14. Notations

Notation	Stage	Description
X_1Sup	Supplier	Raw material cost
X_2Sup	Supplier	Transportation cost
Y_1Sup	Supplier	Supplier capability factor
$Z_1Sup\text{-}Man$	Supplier	Defect-free parts per million
$X_1Man.$	Manufacturer	Advertisement cost
X_2Man	Manufacturer	Transportation cost
X_3Man	Manufacturer	Investment in sustainability design
Y_1Man	Manufacturer	CO2 emission
Y_2Man	Manufacturer	Average reputation factor
$Z_1Man\text{-}Dist$	Manufacturer	Number of green products
X_1Dist	Distributer	Transportation cost
X_2Dist	Distributer	Personnel cost
Y_1Dist	Distributer	Service diversity
$Z_1Dist\text{-}Ret$	Distributer	Time deliveries
X_1Ret	Retailer	Procurement cost
Y_1Ret	Retailer	Average customer satisfaction factor

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(2014), we observe that our results are more similar to Tajbakhsh and Hassini (2014) than Mirhedayatian *et al*. (2014). This is because our model and Tajbakhsh and Hassini (2014) model are based on the same structure. The only difference is the use of slacks in Tajbakhsh and Hassini (2014) model.

CONCLUSION AND FUTURE WORKS

In this paper we propose a TCO-DEA framework for evaluating the quality of multi-tier suppliers in global supply chains. The proposed framework involves two main steps. In the first step, the total cost of ownership of each supplier is calculated using different qualitative and quantitative cost categories. These costs can be categorized into manufacturing, quality, logistics, social and environmental, design costs, after sales, and price. In the second and the final step, network data envelopment analysis is applied to compute the efficiency of each supplier with respect to the TCO cost categories.

The strength of the proposed framework is that it takes into account the network structure of the supply chain and can deal with *n*-tier suppliers. Besides, it helps the decision maker identify the most efficient supplier and improvement areas for an inefficient supplier to become efficient which can be the basis of supplier development programs selection at focal organizations. For example, training and implementation of quality tools, committing of resources, and relationship management.

The limitation is the lack of real data in our study. The numerical examples are based on random data generated by Excel. Future research can include:

Table 15. The data of the Iranian beverage case study

Stage	Inputs Outputs	DMUs									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Supplier		290	300	288	320	290	340	325	330	349	295
		220	345	350	330	275	210	370	250	320	335
		1250	1295	1320	1259	1320	1349	1329	1276	1293	1302
		999961	999966	999954	999968	999947	999938	999961	999955	999928	999958
Manufacturer		104	125	110	105	135	142	159	130	115	100
		139	125	155	132	149	176	125	192	156	145
		394	452	329	442	526	349	527	397	309	403
		0.00645	0.00599	0.00654	0.00556	0.00599	0.00641	0.00562	0.00549	0.00599	0.00575
		3	2	3	3	2	3	3	2	3	3
		490	523	539	597	479	623	589	532	508	639
Distributer		127	147	247	147	184	194	204	215	167	156
		29	32	28	35	32	35	29	26	37	30
		170	189	172	193	219	189	190	153	189	210
		9590	9721	10372	10333	9742	11036	11553	10846	10423	10467
Retailer		102	112	130	100	139	149	147	125	130	104
		4	2	3	4	4	3	4	2	3	2

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Table 16. Calculation results of the Iranian beverage case study

DMUs	Based on Zhu, 2009						Tajbakhsh and Hassini, 2014						Mirhedayatian, 2014	
	Ω*	Ωs_{up}	Ωm_{an}	Ωd_{ist}	Ωr_{et}	Rank	Ω*	Ωs_{up}	Ωm_{an}	Ωd_{ist}	Ωr_{et}	Rank	Ω	Rank
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	0.929	0.961	1	0.981	0.446	6	0.929	0.961	1	0.981	0.446	6	0.250	8
3	0.933	1	1	0.878	0.577	5	0.945	1	1	0.935	0.577	3	0.467	7
4	0.966	0.903	1	0.978	1	2	0.966	0.903	1	0.978	1	2	0.604	4
5	0.912	1	0.849	0.998	0.729	8	0.913	1	0.849	1	0.731	8	0.243	9
6	0.953	1	0.943	1	0.760	3	0.925	1	1	0.875	0.503	7	0.500	5
7	0.926	0.894	1	0.940	0.694	7	0.936	0.894	1	1	0.680	5	0.700	3
8	0.761	0.898	0.708	0.843	0.400	10	0.830	0.898	0.803	1	0.400	10	0.500	6
9	0.882	0.830	1	0.875	0.577	9	0.907	0.830	1	1	0.577	9	0.800	2
10	0.941	0.977	1	1	0.481	4	0.941	0.978	1	1	0.481	4	1	1

- Other cost categories that are critical to buyer-supplier collaboration.
- Other cost categories related to different types of supply chains.
- Results validation with other multi-tier supplier quality evaluation techniques.

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Chapter 29
Location Planning of Electric Vehicles Charging Stations

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ABSTRACT

In this chapter, the authors address the problem of location planning of recharging stations for electric vehicles. This involves determining the best locations for charging stations in order to ensure that vehicles are charged enough for rendering a service when needed. The problem objective is to maximize the flow coverage for the electric vehicles through optimizing the number of recharging stations and their specific type at each station. Flow coverage is referred to as the ratio of car flows that are covered with regard to a special budget level. It also tries to minimize the locating cost related to these infrastructures. A genetic algorithm-based approach is proposed. Numerical application is provided, and results compared against branch and cut algorithm. The proposed approach performs better.

1. INTRODUCTION

Nowadays, many governments are involved in reducing air pollution arising from vehicle movements and saving energy at the same time, especially in big cities where it can be a big dilemma (Wang and Linn, 2013). Transportation management is one of the fundamental processes in maintaining sustainable and green supply chain (Tundys, 2017). Using public transport is a good alternative to personal cars; however, it is not applicable at all the times.

Using shared cars is another alternative to this problem, which lets users have their personal privacy. It also decreases the number of cars on the streets. It is also a good alternative for doing urban trips.

There is even a better solution to this problem, i.e. using electric vehicles in the carsharing companies as an alternative to fossil fuel-based vehicles. In this way, they can reduce the fuel consumption and decrease the air pollution significantly.

There are some challenges regarding electric vehicles usage which currently limits their application in carsharing companies. Planning of supply chain activities is one of the most important enablers in initiating an efficient collaboration between logistics partners. Efficient resource planning will result in

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lean supply chain management and eliminates the waste in time and money. This is the key in realization of business goals and profit management (Grzybowska et al., 2014).

In the context of electric vehicles usage in carsharing industry, facility planning is one of the main concerns in supply chain planning activities. It is defined as the process of identifying the location, number and types of facilities to meet the customer needs as well as the business needs. Sustainable planning is a crucial factor in obtaining environmental objectives (Awasthi et al., 2014). Selecting the most efficient and economic growth strategy, while satisfying the demand, has always been a big challenge on the way of carsharing companies (El Fassi et al., 2012). It specially comes in to attention when we are talking about electric vehicles. Operational and constructional costs of green supply chain have always been a concern in initiating green supply chain strategies (Tundys, 2017).

Considering the charging limit of battery of an electric vehicle and its energy consumption during trip, drivers can think of various charging strategies such as charging the vehicle in the middle of the trip in order to avoid running out of electricity charge (Wang and Lin, 2013). Facing these challenges needs more in-depth studies in order to investigate the best solutions and possible approaches to deal with this issue (Kuby and Lim, 2005).

In this paper, we perform a study on one of the main challenges in carsharing industry which is location planning for charging stations of Electric Vehicles. This involves determining the best locations for placing charging stations for electric vehicles in order to ensure that vehicles are charged enough for rendering a service when needed.

The mathematical problem objective is to maximize the flow coverage for the electric vehicles through optimizing the number of recharging stations and their specific recharging technology type at each station. Flow coverage is referred to the ratio of car flows that are covered with regard to a special budget level. It also tries to minimize the locating cost related to these infrastructures. Our work is based on the model developed by Wang and Lin, 2013. We implement the improved version of the problem through branch and cut algorithm in AIMMS (Advanced Interactive Multidimensional Modeling System) and Genetic Algorithm in Matlab. The results of our model show superior performance over the original model.

The rest of the paper is organized as follows. In section 2, represents the problem statement. In section 3, we present the literature review on electric vehicles carsharing, issues in managing electric vehicles fleet, and location planning in this industry. Section 4 includes proposed solution approach for location planning problem for the recharging stations. Section 5 represents and compares the achieved results. Section 6 presents the conclusions and future works.

2. PROBLEM STATEMENT

Battery power limitations in electric vehicles forces the drivers to keep their cars charged at all the times. Therefore, finding a re-charging station for these drivers can be a very important concern in order to complete their trip and also for companies to respond to their customers' needs. Considering budgetary constraints, finding the right number of required charging stations and also installing them in the right places so that they can be accessible for all customers are some of the challenges that carsharing companies need to address. The paths and trips with more demands could be the base for the company to make the distribution of stations, but the question is how to use this information for this purpose.

The challenges in location planning of recharging stations for EVs (Electric Vehicles) is not limited to finding the right locations and number of the stations to be installed, but also other issues such as

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choosing the right kind of recharging technology for each of the stations. Since there are different kinds of technologies for recharging the EVs' battery, it is important to find a trade-off between the different kinds of infrastructures' cost and their recharging rates. For example, while a fast recharging station's rate is 2 km/min, its cost is 20,000 $ per each station. On the other hand, cost of a slow recharging station is only 4000$, but its rate is 0.133 km/min. So, it is important to find the best combination of different available charging types in each station based on customer requirements.

3. LITERATURE REVIEW

This chapter discusses about carsharing, how it works, its applications, history, and so on. It also gives an overview of electric vehicles and their application in carsharing industry as well as costs and benefits regarding these vehicles.

Then, we present the approaches available in literature to deal with location planning problem of recharging stations for carsharing vehicles. Finally in the last part, performed studies and researches in each of this area are reviewed and research gaps are presented.

3.1. What is Carsharing?

A carsharing company usually consists of small to medium sized fleets of vehicles available for members at specific stations spread over the city (Shaheen *et al.*, 1999). They can be rented for different periods of time from some hours up to some days.

Since carsharing is considered as an alternative to private car usage, its environmental and social objectives are considered more important than business and financial purposes (Car2go, 2012).

Promoting community transit and environmental concerns are some of the main reasons behind governmental support for these sorts of businesses. It also leads to decreasing personal car ownership, reducing the distance travelled by the cars, decrease in fossil fuels consumption and greenhouse gases' emission (Martin and Shaheen, 2011).

3.2. History

Car sharing history goes back to as early as 1948 by a company named Sefage (Selbst Fahrer gemeinschaft) in Zurich Switzerland. After that, a series of other CSOs (Car Sharing Organizations) in the 1970/80 era around Europe were established like: PROCOTIP in Montpelier and Witkar in Amsterdam (Harms and Truffer, 1998).

Late 1980's was the start of more successful experiences in carsharing business all over Europe especially in Switzerland, Germany, Austria, the Netherlands, Denmark, Sweden, Norway, Italy and Great Britain (Shaheen *et al.*,1999).

Various projects have been initiated in international level to mitigate the sustainable urban logistics problem, such as BestUFS (BEST Urban Freight Solutions), SUGAR (Sustainable Urban Goods logistics Achieved by Regional and local policies), TRAILBLAZER (Transport and Innovation Logistics by Local Authorities with a Zest for Efficiency and Realization), STRAIGHTSOL (Strategies and measures for smarter urban freight solutions), C-LIEGE (Clean Last mile transport and logistics management for

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smart and Efficient local Governments in Europe), GRASS (Green And Sustainable freight transport Systems in cities), and COFRET (Carbon Footprint of Freight Transport) (Sierpinski, 2017).

It was demonstrated across North America in the 1980's by two carsharing companies, first one called Mobility which was operated as a Purdue University research program from 1983 to 1986 in West Lafayette Indiana and second one called Short Term Auto Rental (STAR) which was operated as a private enterprise from 1983 to 1985. However, both of them stopped working after a while. Mobility Enterprise was deployed as a research experiment and STAR failed in the middle way of the three-year planned program (Shaheen, 2005).

Auto-Com, the first and oldest CSO of North America was located in Quebec City. It was started as a nonprofit cooperative and then after was changed to for-profit business in 1997. Communauto Inc. was established by Auto-Com group in Montreal in September 1995 as a for-profit business. It is now one of the main carsharing companies in Quebec Province in Canada (Shaheen *et al.*, 1999).

3.3. Carsharing vs. Traditional Car Rental

Carsharing is an alternative to private car usage. Its difference with respect to car rental is that people can rent the cars only for special periods of time (some hours), as well as longer times (some days), and pay for that time.

The second difference which makes it more practical for the users who don't have a car is that they can access the cars at any time during the 24 hours of a day. Since the parking stations are spread around the town, everybody has a chance to reach a car at the nearest station (What is Carsharing, 2010).

3.4. What is an Electric Vehicle?

The Motor

These cars generally have one or more electric motors with a total power ranging from 15 to 100 KW depending on the size, usage and desired performance. E.g. 48 kW (65 hp.) for a small 4-seater saloon.

Batteries and Range

The battery bank supplies energy provided:

- Recharging from an external source via cable
- Vehicle deceleration, where the engine works as a generator.

The battery capacity is within a range of 5 to 40 kWh, with a total voltage of between 300 and 500V. The vehicle's range depends directly on the battery's capacity and also on the type of journey (flat, varied, urban, etc.), the driving mode and the accessories used (headlights, heating, air-conditioning, windscreen wipers, other accessories).

The manufacturers announce an average driving range of 150km (Communauto, 2014).

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3.5. Electric Vehicles and Fleet Management

The increasing use of electric vehicle fleets is a response to the political commitment to reducing the carbon usage of the transport sector (Touati-Moungla and Jost, 2010).

Electric vehicles can significantly reduce emissions that contribute to smog, particularly in urban areas, and to climate change by displacing the demand for gasoline. The policies regarding environmental and sustainable development issues of governments and private corporations, therefore, drive an interest in electric vehicle technology for fleets (Touati-Moungla and Jost, 2010).

Electric vehicles use expensive and new technology. Since they are partly- or fully-powered by electricity, and because their mechanical design is different, the higher upfront capital costs can be offset through reduced fuel and maintenance expenses over their service life in a fleet (Wen-liang *et al.*, 2009).

Because vehicles in public or commercial fleet service often are used for more hours and mileage than personal vehicles, and fleet managers are eager to use electric vehicles within their operations, it is expected that the return on the investment in electric vehicles will be more economically attractive for fleet application (Wen-liang *et al.*, 2009).

3.6. Benefits and Costs of Electric Vehicle in Carsharing

Carshare schemes increase the flexibility of public transport (PT) offer in a city and provide quality of life benefits further enhanced by use of electric powered cars.

Less pollution i.e. emissions and noise, due to less traffic and use of electric vehicles, reduced environmental impacts resulting from reduced mileage, clean, quiet vehicles, reduced congestion and delays, and more sustainable transport leads to improved quality of life in the city are the main advantages of using electric vehicles in carsharing organizations (Ion *et al.*, 2009).

On the other hand, costs are associated with the provision, and subsequent maintenance of the electric vehicles. A back-office system for handling charges and membership, and with the provision in the city for infrastructures of parking spaces equipped with facilities for re-charging the electric vehicle's batteries are some of them (He *et al.*, 2013).

3.7. Challenges in Electric Vehicles Carsharing

When it comes to the use of electric vehicles in carsharing, various challenges are faced by the industry. Customers' attitudes and priorities intuitively have effects on the demand. On the other hand, media and education affect the way people think of using such a system. Encouraging people to rent the electric vehicles instead of the fuel ones is one of the challenges that companies are constantly facing. Environmental awareness and promotional offers may be some of the ways to face these sorts of human related issues.

From the industry aspect, there is still a lot to deal with electric vehicles. Battery power shortage, long time of battery recharging, and dealing with the possible technical issues after depreciation are some of them.

While there are some fast charging technologies for EVs, they are still very expensive for many companies to install and offer these options to their customers. Cutting battery costs while improving its efficiency and power, reducing the vehicle weight, and reducing the cost of electric drive systems are some of the technical issues that industries are facing with.

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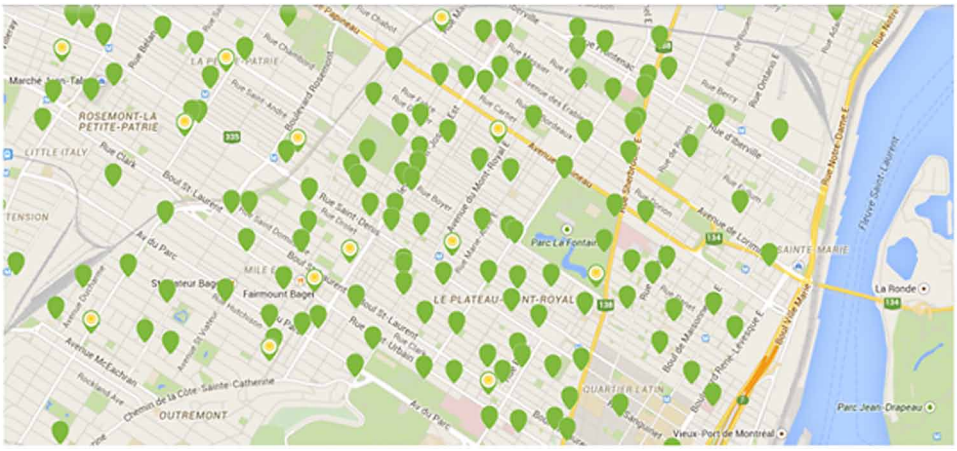
Figure 1. Network map of Communauto's stations across Montreal (Communauto, 2014)



Battery limitations make it crucial for the companies to provide recharging stations as much as possible accessible for the customers. The right number of recharging docs at each station and choosing the right type of technology according to the customers' needs, installation costs and budgetary constraints are some the crucial issues that business companies in the carsharing industry have to overcome. Therefore, solving these issues is a great help for extending the use of EVs in the future and considering it as a future business model for the carsharing industries.

3.8. About Communauto Inc.

Communauto Inc. is a carsharing company privately owned and founded in Quebec City in 1994. It was then merged with its competitor, Auto-com in 2000. After that, Communauto expanded its activity in four areas of Quebec province namely Québec, Montréal, Gatineau and Sherbrooke. Its members reached to the number of 36000 in total in May 2012 with 883 vehicles in use across 331 stations spread through the city (Communauto, 2014).

The network map of the stations across Montreal is shown below:

3.9. Research Reviews

It is more challenging in electric vehicles than fuel vehicles to manage the facilities, their associated costs and infrastructures in the carsharing industries. A limited number of researches have been done in the field of electric vehicles location allocation and refueling strategies. Optimization plays a main role when it comes to fleet management in electric vehicles. Electric vehicles produce very low emissions, but they are still offered in a limited range. They can be used for short term trips and they can be charged at their holding locations. Basically, electric vehicles in carsharing systems operating in standard roadways must meet Federal Motor Safety Standards (FMVSS), (Barth & Todd, 1999).

While air pollution, gas emissions and fossil fuels increasing consumption are pushing governments to use more sustainable means of transport, limitations and dilemmas makes it more challenging to use these source of energies for vehicles.

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Insufficient capacity of charging stations, shortage of infrastructure, and unsuitable EV charging policies are some of the main challenges in implementation and maintenance of EVs. Implementing EV carsharing is a multi-stage process that involves investigating number of influencing factors like provision of infrastructures that are aligned with EV requirements, charging time required for each vehicle, accessible charging locations, and quality charging systems (Turon, 2018).

Establishing an accessible recharging system for electric vehicles is a very important factor in encouraging people to use more EVs when it comes to choosing which kind of vehicle to rent. As a result, due to critical challenges regarding the installation costs and procurement of infrastructures, developing a comprehensive model for recharging station planning is a concern for both government and researchers (Wang & Lin, 2013).

Alternative-fuel stations availability increases the customer acceptance of the electric vehicles (Kim & Kuby, 2012). In this study, a MIP (Mathematical Integer Programming) model was developed for optimizing the location planning of hydrogen refueling stations. Their model maximized the number of flows which can be refueled in the network. It is assumed in their model that the customers do not deviate from their pre-planned path in order to refuel their vehicle. They assumed that there is an upper tolerance limit for drivers to deviate from their original path.

There are several algorithms in order to solve optimization and mathematical problems. While, some of them like branch and bound and branch and cut algorithms give exact solutions to the problems, some others like heuristic algorithms give local optimum solutions that in many cases are close to the exact optimum solutions. While some studies have used exact algorithms, some other have preferred to use heuristic algorithms and in some case multiplication of different heuristics in order to solve optimization problems. For large scale cases, while the exact approaches take long time to solve the problem, heuristics take shorter time to solve the problem. Also they are good substitute when there is no exact solution for a kind of optimization problems.

Careful planning is a must to locate the stations in the nearest distance from customers' needs (Wang, 2011).

https://www.facebook.com/pages/Parc-R%C3%A9gional-Des-Sept-Chutes/162557883884623 Fontana (2007) solved a routing problem for electric vehicles through robust optimization, while taking in to account uncertainty, congestion and energy constraints. Wang (2007) considered the charging time as a decision variable in order to calculate the minimum required charge to complete the journey. It can be defined based on the required charge that each car needs to complete the journey. On the other hand, Wang (2008) and Wang & Lin (2009) used the available charge and used added charge at a station as a substitute to recharging time variables. None of them considered the percentage of flow coverage on the base of different available budgets. All of these researches have used branch and bound algorithm to solve the location planning problems.

Wang and Lin (2013) assumed all three types of recharging stations, including slow-recharging stations, fast-recharging stations and battery-exchange stations. Furthermore they formulated a separate optimization problem to maximize the flow coverage based on the available budget. They also used branch and bound algorithm.

Exact algorithms are also used in Labbe *et al.* (2004). They implemented a branch and cut algorithm for solving a plant cycle location problem. They developed a MILP (Mixed Integer Linear Programming) problem with the objective of minimizing the total cost. According to their result, the branch and cut algorithm in their problem could solve up to 120 customers and 16 potential plants in a real-world data set.

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Also, Catanzaro *et al.* (2011) solved a Partitioning-Hub-Location-Routing Problem (PHLRP) through developing an Integer Programming Model (IP Model) and solved the problem with branch and cut algorithm. According to their computational experiments, the proposed approach was able to solve up to 20 vertices of instances in PHLRP problem.

Heuristic algorithms are also widely used in recent location planning studies. Lim and Kuby (2004) assumed multiple combinations of refueling facilities. Kuby and Lim (2010) solved a proposed MILP problem using three different heuristics algorithms. According to their results, all of these methods perform fairly well, but they give only local optimum solutions. They compared two cases of basic scenario in which each vehicle passes from each station at most once and extended scenario in which vehicles can visit each node more than once as well.

Duron *et al.* (2000) used heuristic algorithms to find the stations with more probability of running out of cars based on the current status of the system. The first algorithm was to use a truck with a fixed circuit to cover the lack of vehicles in the system. The objective of the system was to minimize the number of not responded demands. The second algorithm which named reactive algorithm does not consider the circuit fixed, but is designed to visit the next station by the truck based on the state of the whole system. According to the results, the second algorithm works much better than the first algorithm in terms of minimum not satisfied demands.

Genetic algorithm is one of the popular heuristic methods used in this research area. Tohyama *et al.* (2011), developed a model for incapacitated facility location planning and solved it through genetic algorithm. They have solved an NP_hard problem through a genetic algorithm model based on a rough estimation of a of optimal facility locations. The estimation is performed based on the ratio of the facility placement cost and the cost to users of the facility. The mutation function then searches the solution spaces with more probable good solution. In this way the whole space is being searched more efficiently. A comparative study with other proposed methods in the past are done in order to verify their methods performance.

According to Lim and Kuby (2010), since in real cases there is a need for combinations of stations, it may be impractical to generate and solve the facility location problem with MILP methods. Therefore, they developed some heuristic algorithms for locating the refueling stations in carsharing industry. They compared the performance of greedy-adding, greedy-adding with substitution and genetic algorithm and implemented them for a case study in Florida.

Along with theses algorithms, there are some other approaches which are popularly used in location planning as well. As an example, Di Febbraro *et al.* (2012) proposed the complex dynamics of the system, using a discrete event system simulation. They formulated a Discrete Event Model for this purpose which was based on a user-based methodology in order to achieve an optimal relocation policy. This methodology also reduces the number of required staff to relocate vehicles and identifies the minimum number of vehicles needed to respond system demands.

Also, Ion et al (2009) used a hybrid approach to select the station sites for electric vehicles of a carsharing service. The if-then rules were used to aliment a fuzzy logic through modeling the customers' preferences. Preferences of habitants of each urban area were considered in this study.

While there have been some studies which have proposed some models to achieve a solution for location allocation problem of recharging stations for electric vehicles, very few have tried to do a comparison study to figure out which approach gives better solution than the others. Proposing a new optimization problem for these sorts of problems may not be a new achievement in this area, since there are lots of optimization problems that are proposed for this purpose and they are in some cases more or less similar

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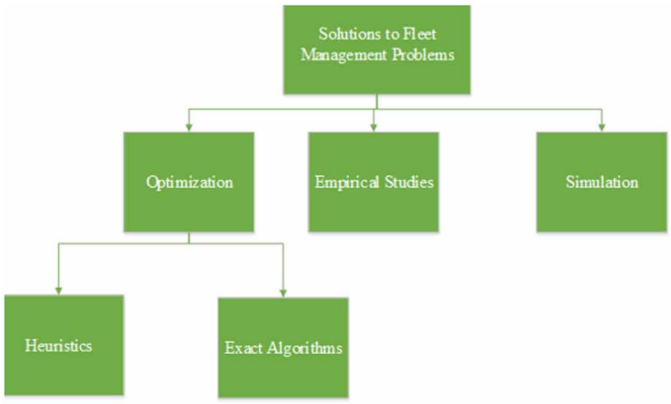
Figure 2. Fleet management solution approaches



to each other and even adaptable to other real world cases as well. In this paper, we go through some comparative studies in order to find the best approach to solve the location planning problem. Considering the model proposed in Wang and Lin (2013) as a base, we implement our proposed model after some editions on the base model through an exact algorithm and a heuristic algorithm and compare the results.

3.10. Approaches

Fleet management has been a concern for carsharing companies for many decades. There are many ways used to manage and optimize the location planning of facilities in carsharing industry. Some of the main ones are optimization approaches, empirical studies and simulation. In Figure 2, the different categories of solution approaches to solve fleet management problems, are shown through a chart.

Optimization

In this paper we will go through some optimization approaches to solve the location planning problem. Optimization or mathematical programming is referred to the process of finding the best feasible values for some objective functions (maximizing or minimizing), while satisfying some given domains or constraints.

Some literatures divide optimization in to two categories of algorithms including exact algorithms and heuristic algorithms.

Heuristics

Heuristics approaches are algorithms that find local optimum solutions among all possible ones, but they do not have any guarantee to find the best possible solution. Therefore they may be considered as approximately accurate algorithms. They are typically used for solving real-life issues because of their acceptable speed and ability to solve large instances. Lim & Kuby (2010), Tohyama *et al.* (2011) and Arostegui *et al.* (2006), Yang *et al.* (2007) and Zhang *et al.* (2006) have used some sorts of heuristic approaches for facility location problems in their works.

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Genetic Algorithm

Genetic Algorithm (GA) is one of the popular heuristic algorithms which finds local optimum solutions near the global optimums. GA is commonly used to solve MIP problems and is an evolutionary algorithm which is considered as a subset of artificial intelligence. It is a search heuristic (sometimes called metaheuristic), that mimics the natural selection process of genes. The techniques used in this method are inspired by natural evolution, like inheritance, mutation, selection, and crossover.

It is one of the heuristic algorithms that can give a locally optimized solution to optimization problems. Genetic algorithm continuously modifies a population of individual solutions. In each iteration, the genetic selects individuals from the current population based on a cross over definition to be parents and perform the crossover and mutation to produce off-springs for the next generation.

After successive generations, the generated population evolves to an optimal solution. It can be applied to the mixed integer programming problems, while some components are restricted to be integer-valued (Wikipedia: Evolutionary algorithm, 2014). Lim & Kuby (2010), Tohyama *et al.* (2011) and Arostegui *et al.* (2006) have used genetic algorithm approach for their location planning optimization problems.

Exact Methods

Exact methods are known as approaches which find the exact optimum solutions for optimization problems. They guarantee to find the best possible response for the problem in case that there is enough time and space.

A simple enumeration like what is done in many other approaches is out of question, so exact methods must utilize more clever approaches (Wikipedia: Cutting Plane Methods, 2014).

Hewitt *et al.* (2010), Li *et al.* (2011) and Nagy, and Salhi (2007) have used some sorts of exact algorithms in their studies. Here, we review three of the main exact methods as follows:

Branch and Cut Algorithm

Branch and cut algorithm is an exact algorithm that gives the global optimum solution for a problem. It is widely used for solving integer programming problems. It consists of a combination of a cutting plane method and branch and bound algorithm. The procedure involves running a branch and bound algorithm and applying cutting planes to tighten the LP problem relaxations of the main MILP problem. It is a very successful method in solving MIP problems and guarantees the optimality in the solutions.

It is not easily possible to solve a general integer programming problem efficiently through only using a cutting plane method. Therefore it is necessary to branch the problem which results in branch and cut algorithm. Also a pure branch and bound algorithm can be sped up using a cutting plane algorithm. So, a combination of them would give a boost to the efficiency and speed of the solution approach. Labbe *et al.* (2004), Catanzaro *et al.* (2011) and Rodriguez-Martin *et al.* (2014) have implemented branch and cut algorithm for solving their facility location problems.

In the following paragraphs, the branch and bound algorithm and cutting plane method are described in details:

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Branch and Bound Algorithm

Branch and bound algorithm starts with modeling the solution space as a tree and traverses through the tree to explore the most promising subtrees. This is called branching. Bounding is done through computing the upper and lower bounds for checking the optimum value of the objective function in each of the subtree in each iteration. It is continued till the point that either there are no more subtrees to break the problem or if it is continued, the later responses will be inferior.

This method was first suggested by A. H. Land and A. G. Doig in 1960. The name first was introduced in a work by Little *et al.* on traveling salesman problem in 1963. Goel *et al.* (2006), Verter (2011) are some of the recent works who have used branch and bound algorithm for solving location allocation problems.

Cutting Plane Algorithm

Cutting Planes Algorithm is one of the exact methods that are used for integer programming problems. They have been proven to be a very useful approach from the computational aspect, especially when it is combined with branch and bound algorithm.

This method works through solving some sequences of linear programming relaxations of the main integer programming problem. The relaxations in some steps, improve in order to give better approximation to the integer programming model, at least in the neighborhood of the optimum solution.

It has been used to solve various integer programming problems including traveling salesman and maximum cut problems.

It is very popular to use cutting planes algorithm in order to solve mixed integer programming problems (MILP), as well as general, not necessarily differentiable convex optimization models.

Applying cutting planes method to MILP was first introduced by Ralph E. Gomory and Václav Chvatal in 1990 (Wikipedia: Cutting Plane Methods, 2014). Laporte *et al.* (1986) and Gollowitzer *et al.* (2013) have used this algorithm in their location planning researches.

In this study, we are going to improve a MILP problem proposed by Wang & Lin (2013), and then we implement it through two different approaches to compare the results both with each other and with the Wang & Lin (2013).

Two approaches selected for this purpose are as follows:

1. Using CPLEX through AIMMS software which gives a global optimum solution through using a combination of cutting planes algorithm and heuristics.
2. Genetic Algorithm which heuristically searches for a local optimum solution near to the global optimum

4. SOLUTION APPROACH

Optimization (also referred to mathematical programming or mathematical optimization) is the process of selecting the best set of elements out of some available sets of alternatives with regard to some criteria.

More generally, in applied mathematics concepts, optimization consists of finding the best available values for some objective functions (maximizing or minimizing), while satisfying some given domains or constraints.

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In this paper, we are going to improve a MIP problem proposed by Wang & Lin (2013), and then implement it through two different approaches, compare the results with each other, and with the Wang & Lin (2013).

While there have been a number of papers which have proposed a mathematical problem for optimizing the carsharing services for electric vehicles, there are less who have compared different approaches to achieve a more reliable answer. In this study, we try to cover this gap through a comparison study to find the best approach.

Two approaches for this purpose have been selected:

1. MIP model development using AIMMS software which uses CPLEX to give an optimum value for the problem
2. Genetic Algorithm which heuristically searches for a local optimum solution near to the global optimum

4.1. Locating Multiple Types of Recharging Stations for Battery-Powered Electric Vehicle Transport (Wang & Lin, 2013)

In the beginning, we start with explaining the mathematical problem proposed by Wang & Lin (2013) in order to improve it and use the modified model as a base for the comparison study. The reason to choose the proposed optimization model in this research was that the author found this models comprehensive enough in order to be applied to other case studies as well. In their model, different combination of recharging technologies based on their recharging rate and locating cost, along with different combination of paths and nodes can be considered. So, there is enough flexibility in chosen models in order to apply them for other cases as well.

Wang and Lin (2013) proposed a mixed integer programming for maximizing the available carsharing services for the customers for a carsharing company. They proposed their model specifically for the electric vehicles which have the challenge of having enough charge for desired distances according to the limitations of installing electricity recharging stations in the right places in order to be accessible for the users.

They solved the problem through a LINGO's BRANCH and BOUND method (Thornburg and Hummel, 2003). The results have been brought in the application results section in order to make the comparison study.

There are two models proposed in this study. The first one is to solve a MIP problem which minimizes the installation cost of the recharging stations according to different locating capacities. This model consists of four sets of variables including 1 binary, 1 integer and 2 continuous.

The second model is also a MIP problem that maximizes the number of covered flows in the model. The output of the first model is the optimum number/local optimum number of locating capacity. It brings the minimum cost that is used as an input in this model in order to find the percentage of covered flows based on the different budgetary constraints.

The second model consists of five sets of variables including 2 binaries, 1 integer and 2 continuous. In this problem, we have k kinds of charging stations with different charging rates and installation costs.

These models were implemented on a project for the recharging station planning in an Island called Penghu, located in Taiwan.

The key elements used in these models are as follows:

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Sets:
p: Paths
k: Recharging station types
i,j: Nodes or locations
Variables:
F(p): binary, 1 if flows in path *p* is covered, 0 otherwise
Y(p,i,k): binary, 1 if a vehicle is recharged using a type *k* station at node *i* on path *p*, 0 otherwise
X(i,k): Integer variable, the number of type *k* stations located at node *i*
B(i,p): Non-integer variable, available range (km) in the battery at node *i* on path *p*
R(i,p): Non-integer Variable, increased range (km) which is gained by being charged at node *i* on path *p*
Parameters:
W(p): Flows per path
t(i,p): time of being charged at node *i* on path *p*
β(*k*): Recharging rate for each kind of recharging stations (km/min)
γ: Battery's maximal charge (km)
L: Available Budget
U(i,k): the maximum number of type *k* stations that can be located at node *i*
C(*i,k*): locating cost of installation of a type *k* recharging station at node *i*
d(*j,p,i)*: distance between nodes *i* and *j* on path *p*
S(k): Vehicle sharing of a type *k* recharging station
1st Model: Minimizing the installation cost of the recharging stations
2nd Model: Maximizing the flow of electric vehicles passing each path per hour:

4.1.1 Improved Model

In the improved version, we have added one more constraint (constrain 7 in the minimization and constraint 9 in maximization) which limits the number of recharging stations built at each node to the number of consumed charging station which are really needed for each station. In this way, the approach which is trying to find a solution does not substitute any value for the X (number of charging stations) other than the required number of them which were consumed by the customers. While in first model, X is a variable which can take any number between 0 and U (the locating capacity at each node) only if it satisfies the other constraints even at the max level, in the improved version it is limited to the required number of charging stations according to when there is a need for that (when Y=1). Especially in heuristic algorithms, the process of finding the local optimum solution can face more challenges because there is only an upper bound limit for the variable X.

Improved version can avoid many occasions when randomly the value of X increases in the feasible criteria and makes the locating cost increase unnecessarily.

Revised 1st Model:

$$X\left(i,k\right)=\sum_{p}Y\left(p,i,k\right)$$

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Revised 2nd Model:

$$X\left(i,k\right)=\sum_{p}Y\left(p,i,k\right)$$

4.2. Solution Approaches

In this section some methods which are popularly used in location planning optimization are explained in detail and their application is illustrated.

4.2.1. Branch and Cut Algorithm

Branch and cut algorithm is an exact method that guarantees the global optimum solution for a problem. It has been very successful in solving integer programming problems. This method consists of a combination of a cutting plane method and branch and bound algorithm.

It works through solving a sequence of LP relaxations of the main MIP problem. Cutting plane method improves the relaxation of the problem to more close or approximate integer values for the main integer programming problem. Branch and bound algorithm proceeds by divide-and-conquer procedure to achieve the optimum solution.

It solves the linear program without the integer constraints through regular simplex algorithm. After achieving an optimal solution, if there is a non-integer value for a variable which was supposed to be integer, a cutting plane algorithm is used to find more linear constraints that satisfies the feasible integer points. At this step, the branch and bound part starts. It splits the problem in to two (or more) versions. The new LP programs are again solved by simplex method and the process continues.

Perhaps the most popular branch and cut algorithm is the one that has been used to solve traveling salesman problems.

4.2.1.1. Softwares Used

AIMMS

Advanced Interactive Multidimensional Modeling System or **AIMMS** is referred to a software system which is used for modeling and solving large-scale scheduling and optimization problems. AIMMS Supported solvers include CPLEX, Gurobi, MOSEK, CBC, Conopt, MINOS, IPOPT, SNOPT, KNITRO and CP Optimizer (AIMMS: SOLVERS, 2014).

CPLEX

AIMMS uses CPLEX for solving MILP problems. For the problem we are seeking to solve here, CPLEX is a suitable option. It is a high level performance solver for Linear Programming problems (LP), Mixed Integer Programming problems (MIP) and Quadratic Programming problems (AIMMS: CPLEX, 2014).

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4.2.2. Genetic Algorithm

Genetic algorithm is a heuristic approach which is used for solving the optimization problems so popularly and through approximate methods. It searches rapidly among all possible solutions and finds the best one among the achieved responses. There are some main steps to create the next generation from the current population and repeat it to reach an optimal solution (Genetic Algorithm, 2014):

1. Choosing the right fitness function that can be used as a base for scoring the chromosomes and choosing good ones in order to find a more complete solution

    1. Generating an initial population of chromosomes to start with and use them as the first generation
    2. Selection of which chromosomes will be chosen to be parent of the next generation off-springs.
    3. Crossover to produce next generation
    4. Random mutation in produced off-springs in new generation

In our case, we define the fitness function the same as the objective function. Since we are seeking to maximize (minimize) the objective function, in the selection part, we give the priority to bigger (smaller) values of the fitness function.

For our optimization problem, we have 5 sets of variables including 2 binaries, 1 integer and 2 continuous. Based on the objective function (fitness function), the only variable in the objective function that we have to optimize is a binary variable called F, containing 12 binary values indicating whether or not each one of our popular paths is covered. Therefore, number of chromosomes in this case is 12 based on the number of popular paths for this case study.

In Generation phase, each of the five variables are generated through a random function in MATLAB R2012b. A population size of 200 is used. Then each produced string of chromosomes is evaluated based on the fitness function to verify its score in order to achieve the best value to cover whole paths as much as possible.

In selection phase, we keep the fitter half (0.5) of the current population based on the ranking method for a maximization problem, make it double to reach to the same number of chromosomes and then choose randomly among them. We use the first half to select first parent and the second half to select second parent, so in this way all the best fitted values chosen have equal chance.

To perform matching and producing the off-springs, we randomly choose a crossover point and generate the off-springs using that point.

Finally random mutation is done with the rate of 0.2. The maximum iteration is 100.

In the next chapter, the applications results for the exact algorithm and heuristic algorithm are explained in details and the achieved results are compared.

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Table 1. Trip distribution along popular paths (Wang & Lin, 2013)

Trip distributions along popular routes.

No.	Type of routes	Distance (km)	Maximum flow (scooters/h)
1	Magong → Citou → A → Tongling → B → Chuwan → C → Siaomen → D → Erkan → E → Wai-An → S8 → S7 → S6 → Magong	78.8	3
2	Magong → Citou → A → Tongling → B → Chuwan → C → Siaomen → D → E → Erkan → S8 → S7 → S6 → Magong	66.8	3
3	Magong → Citou → A → Tongling → B → C → Chuwan → S8 → S7 → S6 → Magong	59.6	3
4	Magong → A → Tongling → B → C → Siaomen → D → E → Erkan → S8 → S7 → S6 → Magong	66.4	3
5	Magong → A → B → Chuwan → C → Siaomen → D → E → Wai-An → S8 → S7 → S6 → Magong	78.2	3
6	Magong → A → B → C → Siaomen → D → E → Wai-An → S8 → S7 → S6 → Magong	78	4
7	Magong → Citou → A → B → C → D → Siaomen → S8 → S7 → S6 → Magong	63.2	2
8	Magong → A → Tongling → B → C → Chuwan → S8 → S7 → S6 → Magong	59.4	2
9	Magong → A → Citou → B → C → D → E → Wai-An → S8 → S7 → S6 → Magong	76.2	2
10	Magong → Citou → A → Tongling → B → C → D → E → Wai-An → S8 → S7 → S6 → Magong	76.4	2
11	Magong → S6 → S5 → Beiliao → Guoye → Linto → S4 → Fongguei → S3 → S2 → S1 → Magong	54.9	2
12	Magong → Shanshuei → Shihli → Fongguei → S3 → S2 → S1 → S4 → Lintou → Guoye → Beiliao → S5 → S6 → Magong	56.9	2

5. NUMERICAL APPLICATION

Assumptions

According to Wang & Lin (2013), following parameter values were assumed for implementing the proposed model. We used the same values when implementing the approaches proposed in this paper in order to have comparable results. Table 1 shows the popular paths in this case and their associated passing flows per hour, as well as distances traveled in each path.

Sets:
P= 1 - 12
K= 1 to 3 (slow recharging stations, fast recharging stations and battery exchange stations).
i,j= from 1 to 25
Parameters:
$W(p)$: [3 3 3 3 3 4 2 2 2 2 2 2]
$t(i,p)$: It is the same for all 12 paths and the unit of measurement is minutes.
β(k): The rates (km/min) for slow-recharging, fast-recharging, and battery exchange stations are 0.133, 2, and 4, respectively.
γ: 40 (km)
L: Different budgetary levels
U(i,k): 2, 3, …, 10
$C(i,k)$: for slow-recharging, fast-recharging, and battery exchange stations are thus 4000, 50000, and 20000 $ respectively.
$d(p,i,j)$: Appendix A
S(k): Vehicle sharing of a type k recharging station is set at 1.

- **Name of the nodes:**
- **Installation constraints based on the location of the nodes**

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Table 2. Recharging time in each node

Nodes	Reharging Time
1	56
2	19
3	22
4	28
5	33
6	30
7	30
8	25
9	20
10	32
11	28
12	28
13	20
14	20
15	20
16	20
17	20
18	10
19	10
20	10
21	10
22	10
23	10
24	10
25	10

- The first 12 nodes are considered as attractions nodes called with D1, D2… D12. In the attraction centers, only slow recharging stations shall be installed.
- The next 5 nodes are intersections and called with A, B… E. In these nodes, only fast recharging stations can be sited.
- The last 8 nodes are convenience stores called with S1, S2, …, S8. They can have any of the 3 recharging stations, including SRS (Slow Recharging Stations), FRS (Fast Recharging Stations) and BES (Battery Exchange Stations).

5.1. Results for Implemented Approaches

Results for the MIP model solved using CPLEX approach through AIMMS software can be seen in the following figures. Tables 4 and 6 show the results by Wang & Lin (2013) through Lingo Branch and

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Table 3. Name of the nodes

Nodes	Name
1	D1
2	D2
3	D3
4	D4
5	D5
6	D6
7	D7
8	D8
9	D9
10	D10
11	D11
12	D12
13	A
14	B
15	C
16	D
17	E
18	S1
19	S2
20	S3
21	S4
22	S5
23	S6
24	S7
25	S8

Bound whereas Tables 5 and 7 are results from AIMMS. Figures 3 and 4 are the output of the AIMMS which shows different characteristics of the models and their solvers.

As you can see from Table (4) and Table(5), the main difference between two versions is how the second improved version performs smarter distributions in compare with the initial approach. (*Note*: SRS: Slow-Recharging Station, FRS: Fast-Recharging Station, BES: Battery Exchange Station)

For instance, take a look at the budgetary constraint of 100,000.00 $ in Table (6) and Table (7). According to the assumptions of the case study, the locating cost for SRS, FRS and BES are 4000, 50,000 and 20,000 $ respectively. While initial model has used all the 100,000 $ to install 5 stations of type 3 (BES type, which costs 20,000 for each) at only 1 node called S8, the second model has used this budget to install 12 stations (9 from type SRS which costs 4000 $ for each and 3 from type BES which costs

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Figure 3. AIMMS result for U=5

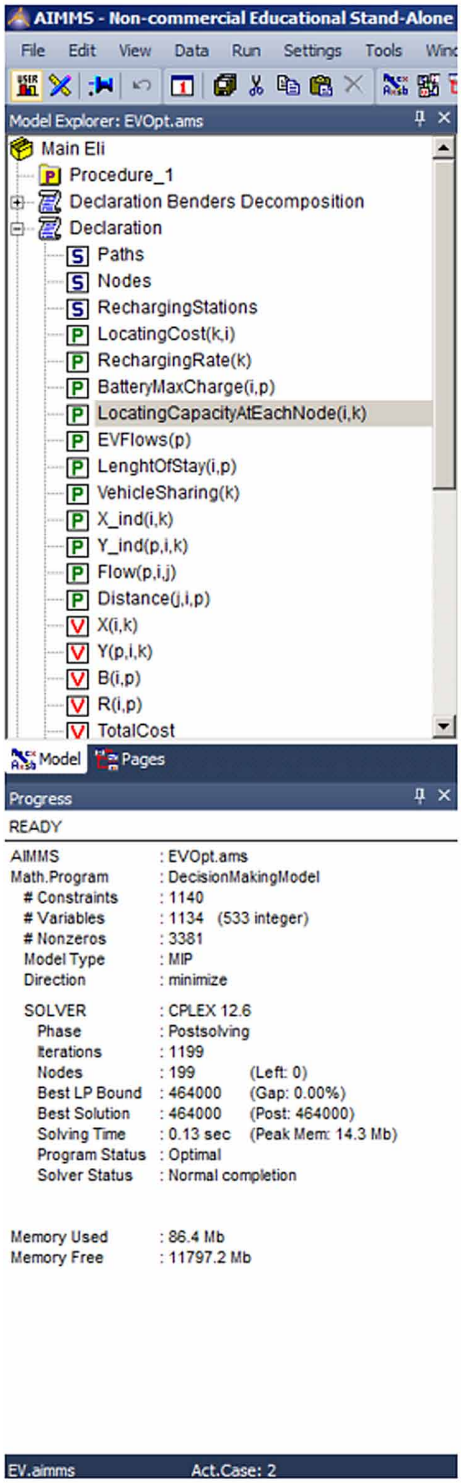

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Figure 4. AIMMS result for budgetary constraint of 464000 $ and U=5

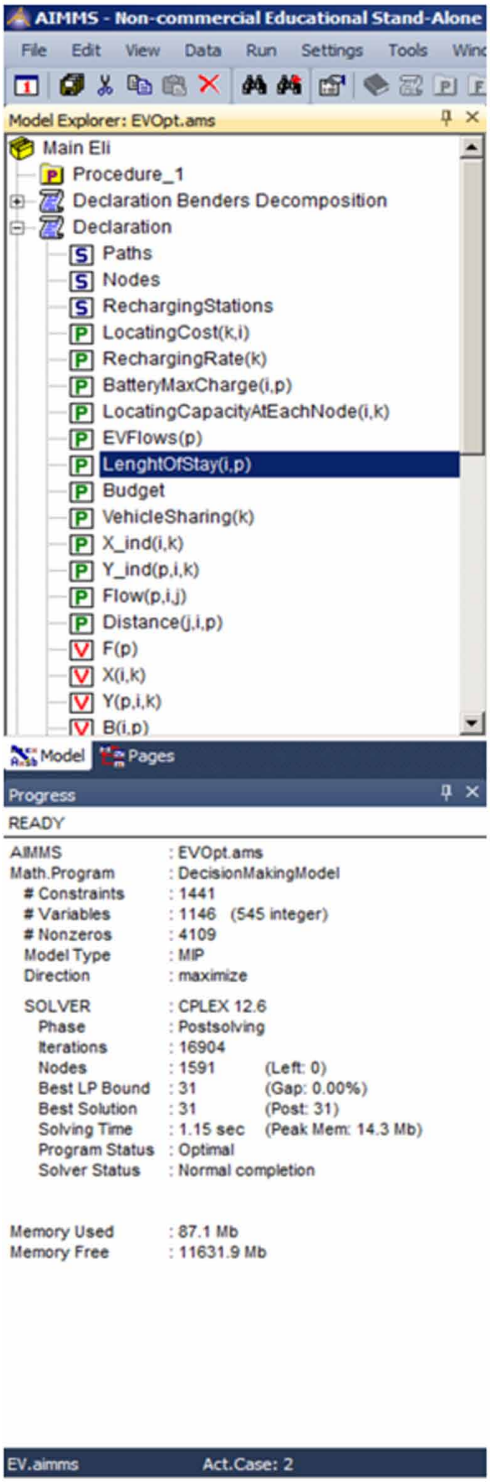

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Table 4. Results of Wang & Lin (2013) approach for cost minimization

with a vehicle range of 40 km

Location capacity	Location (number of SRS)	Location (number of FRS)	Location (number of BES)	Total number of stations (SRS, FRS, BES)	Total location cost (NT$)
5	D1(5), D2(4), D3(3), D5(3), D6(4), D7(2), D10(4), D11(4), D12(4), S4(2), S6(5), S7(4), S8(5)	S8(5), C(3), D(4), E(5)	S7(5), S8(5)	76(49, 17, 10)	1,246,000
6	D1(5), D2(5), D3(5), D4(6), D5(6), D6(6), D7(2), D10(4), D11(4), D12(4), S4(2), S6(6), S7(6), S8(6)	S8(4), D(6) E(3)	S6(3), S7(5), S8(6)	94(67, 13, 14)	1,198,000
7	D1(6), D2(5), D3(2), D6(6), D7(2), D10(4), D11(4), D12(4), S1(2), S6(3), S7(6), S8(7)	D(7), E(6)	S7(7)S7(7), S8(8), S8(7)	78(51, 13, 14)	1,134,000
8	D1(8), D2(5), D3(3), D4(5), D5(6), D6(8), D7(2), D10(4), D11(4), D12(4), S1(2), S6(7), S7(8), S8(8)	D(2), E(7)	S7(7), S8(8)	98(74, 9, 15)	1,046,000
9	D1(7), D2(5), D3(3), D4(9), D5(9), D6(9), D7(2), D10(4), D11(4), D12(4), S4(2), S6(6), S7(6), S8(9)	E(7)	S7(8), S8(9)	103(79, 7, 17)	1,006,000
10	D1(9), D2(2), D3(3), D4(3), D5(6), D6(6), D7(2), D10(4), D11(4), D12(4), S2(2), S6(4), S7(3), S8(5)	D(4), E(3)	S7(10), S8(10)	84(57, 7, 20)	978,000

20,000 $ for each) at 8 different nodes including D2, D3, D4, D5, D8, D10, S4 and S8. In both cases almost the same budget has been spent:

Initial Model: 5*20,000=100,000 $

Improved Model: 9*4000 + 3*20,000=96,000 $

Second model (improved version) has covered 4 paths instead of only 2 paths and in other terms, 10 flows instead of only 5 flows with station capacity of 5 instead of station capacity of 10. There is a significant decrease in the required budget to cover all the paths from 978,000 $ in initial MIP model to 464,000 $ in improved MIP model which is solved through branch and cut algorithm. This is due to the better and smarter distribution of facilities and budget. It is obvious that the required budget has been

Table 5. Results of AIMMS for cost minimization; with a vehicle range of 40 km

Location Capacity	Location (number of SRS)	Location (number of FRS)	Location (number of BES)	Total number of stations (SRS, FRS, BES)	Total Location Cost ($)
2	D2(2), D3(2), D4(2), D5(2), D6(2) s7(1), S8(2)	D (2), E(2), C(1), s8(2), B(1)	S2(1), S4(1), S8(2), S7(1)	27(13,9,5)	602,000.00
3	D2(1), D3(2), D4(2), D5(2), D6(1)s7(1), S8(1)	D (3), E(3)	S2(1), S4(1), S8(3), S7(1)	23 (10, 7, 6)	510,000.00
4	D2(2), D3(2), D4(4), D5(3), D6(1), s7(1), S8(1)	D (2), E(4)	S2(1), S4(1), S8(4)	26 (14,6, 6)	476,000.00
5	D2(1), D3(4), D4(3), D5(3)	D(1), E(5)	S2(1), S4(1), S8(4)	23 (11,6,6)	464,000.00
6	D2(1), D3(4), D4(3), D5(3)	D(1), E(5)	S2(1), S4(1), S8(4)	23 (11,6,6)	464,000.00
7	D2(1), D3(4), D4(3), D5(3)	D(1), E(5)	S2(1), S4(1), S8(4)	23 (11,6,6)	464,000.00

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Table 6. Results of Wang & Lin (2013) approach for path maximization

with a vehicle range of 40 km, and the station capacity of 10

Budgetary constraint (NT$)	Location (number of SRS)	Location (number of FRS)	Location (number of BES)	Total number of stations (SRS, FRS, BES)	Path covered	Number of flows covered (percent)
100,000	–	–	S8(5)	5(0, 0, 5)	P3, P7	5 (16.1%)
200,000	D10(2), D11(2), D12(4), S3(2)	–	S8(8)	18(10, 0, 8)	P2,P3,P7,P11	10 (32.3%)
300,000	D1(3), D2(3), D3(3), D7(2), D10(4), D11(4), D12(4), S3(2), S6(3)S7(3), S8(3)	–	S8(8)	42(34, 0, 8)	P2,P3,P4,P8,P11,P12	15 (48.4%)
400,000	D1(7), D6(2), D7(2), D10(4), D11(4), D12(4), S3(2)	–	S7(5), S8(10)	40(25, 0, 15)	P2, P3, P4, P7, P8, P10, P11, P12	19 (61.3%)
500,000	D1(6), D3(3), D5(3), D6(4), D7(2), D9(2), D10(4), D11(4), D12(4), S8(6)	–	S7(8), S8(9)	55(38, 0, 17)	P2, P3, P4, P7, P8, P9, P10, P11, P12	21 (67.7%)
600,000	D1(9), D2(5), D4(3), D5(6), D6(2), D7(2), D9(2), D10(4), D11(2), D12(2), S1(2), S3(2), S5(2), S6(2), S7(3), S8(2)	–	S7(10), S8(10)	70(50, 0, 20)	P1, P2, P3, P4, P7, P8, P9, P10, P11, P12	24 (77.4%)
700,000	D1(10), D4(3), D5(6), D6(7), D7(2), D10(4), D11(4), D12(4), S1(2), S8(5)	E(3)	S7(8), S8(10)	68(47, 3, 18)	P1, P2, P3, P4, P5, P8, P9, P10, P11, P12	25 (80.6%)
800,000	D1(9), D2(5), D3(6), D5(6), D6(8), D7(2), D10(4), D11(2), D12(4), S3(2), S5(2), S6(2), S7(3), S8(5)	E(3)	S7(10), S8(10)	83(60, 3, 20)	P1, P2, P3, P4, P5, P7, P8, P9, P10, P11, P12	27 (87.1%)
900,000	D1(7), D2(5), D3(3), D4(3), D5(3), D6(8), D7(2), D10(4), D11(2), D12(4), S1(2), S3(2), S5(2), S6(6), S7(10), S8(3)	E(7)	S7(5),S8(9)	87(66, 7, 14)	P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12	28 (90.3%)
974,000	D1(5), D4(3), D5(6), D6(6), D10(2), D11(2), D12(2), S3(2), S7(10), S8(8)	D(4), E(3)	S2(2), S4(2), S7(8), S8(10)	75(46, 7, 22)	P1, P2, P3, P4, P5, P6, P7, P8, P9, P11, P12	29 (93.5%)
978,000	D1(9), D2(2), D4(3), D5(6), D6(5), D7(2), D10(4), D11(4), D12(4), S4(2), S6(4), S7(4), S8(8)	E(7)	S7(10), S8(10)	84(57, 7, 20)	P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12	31 (100%)

decreased to less than the half of the Wang & Lin (2013) approach. One can find similar logic for other budgetary constraints as well.

Genetic Algorithm

According to results of Table 8 (Genetic Algorithm), the location capacity of 5 has the best result among others. In locations capacity of 6 and 7 trials, the algorithm has not used capacity of more than 5 which shows that it has stopped increasing the number of locations at this step. It is obvious from the table that location capacity of 5 is the optimum capacity for this case. These results are achieved after 100 iterations and with population size of 200 which makes it more reliable.

Table 7. Results of AIMMS for path maximiziation; vehicle range=40 km, station capacity = 5

Budgetary Constraint	Location (number of SRS)	Location (number of FRS)	Location (number of BES)	Total number of stations (SRS, FRS, BES)	Path Covered	Number of Flows Covered (percent)
100,000.00	D2(2), D3(2), D4(2), D5(2), D8(1), D10(2)	-	S4(1), S8(2)	12 (9, 0, 3)	P3, P4, P11, P12	10 (32.3%)
200,000.00	D2(2), D3(2), D4(3), D5(2), D10(1), D11(1), D12(1)	E(1)	S8(4), S4(1)	18 (12,1,5)	P2, P3, P4,P6, P8, P11	17 (54.8%)
300,000.00	D2(1), D3(3), D4(4), D5(2), D8(1), D9(2), D10(2), D11(2), D12(2), S2(1)	E(3)	S8(3)	26 (20, 3, 3)	P1, P2, P3, P4, P5, P6, P11, P12	23 (74.2%)
400,000.00	D2(1), D3(3), D4(4), D5(1), D6(1), D8 (1), D10(1)	E(5)	S1(1), S3(1), S8(3)	22 (12,5,5)	P1,P2, P3, P4, P5, P6, P8, P10, P11, P12	27(87.1%)
414,000.00	D2(4), D4(4), D5(3)	E(5)	S2(1), S4(1), S8(4)	22 (11, 5, 6)	P1,P2, P3, P4, P5, P6, P8, P9, P10, P11, P12	29(93.5%)
464,000.00	D2(1), D3(4), D4(3), D5(3)	D(1), E(5)	S2(1), S4(1), S8(4)	23 (11,6,6)	P1,P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12	31 (100%)

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Table 8. GA results for cost minimization; with a vehicle range of 40 km

Location Capacity	Location (number of SRS)	Location (number of FRS)	Location (number of BES)	Total number of stations (SRS, FRS, BES)	Total Location Cost ($)
2	D2(2), D3(2), D4(2), D5(2), D6(2), D9(1), D10(1), D11(1), S7(1), S8(2)	A(1), B(2), C(2), D (2), E(2), S8(1)	S2(1), S4(2), S8(2), S7(1)	32(16,10,6)	684,000.00
3	D3(2), D4(2), D5(2), D6(3), D9(3), D10(3), D11(1)	C(3), D (3), E(3)	S4(2), S8(3)	29 (15, 9, 5)	610,000.00
4	D2(2), D3(2), D4(4), D5(3), D6(1), s7(1), S8(1)	D (4), E(4)	S4(2), S8(4)	23 (9,8, 6)	556,000.00
5	D3(2), D4(1), D5(1), D9(1), D10(1), D11(1)	D(3), E(5)	S4(2), S8(4)	21 (7,8,6)	548,000.00
6	D3(2), D4(1), D5(1), D6(1), D9(1), D10(1), D11(1), S7(1)	D(3), E(5)	S4(2), S8(4)	23 (9,8,6)	556,000.00
7	D3(2), D4(1), D5(1), D6(1), D9(1), D10(1), D11(1)	D(3), E(5)	S4(2), S8(4)	22 (8,8,6)	552,000.00

According to Table 9, we have used the capacity location 5 to maximize the number of covered flows with different budgetary constraints. With different levels of budget, we can compare the results of branch-and-cut algorithm in AIMMS for second model and Lingo Branch and Bound for initial model in the paper. According to the table 9, this project can be finished by 548,000 $ through installing 21 stations in 10 different nodes.

5.2. Location Planning Results Comparison

According to Table 10, while branch-and-cut algorithm has the best performance, genetic algorithm's response is fairly close to the mentioned exact algorithm. So in some cases when there is no exact solution for the problem or for large scale projects with huge solving time, genetic algorithm can be a substitute for branch-and-cut algorithm. Improving the model through adding one more constraint to limit station installation to the required cases only, besides using a widely used algorithm for solving MIP problems, are the main factors which lead to significant decrease in the locating cost in this case.

In Figure 5 below, the difference in the performance of the three methods is illustrated clearly. It is obvious that the exact algorithm has the best performance among others, however genetic algorithm performs almost competitively with this algorithm.

6. CONCLUSION AND FUTURE WORKS

In this paper, we addressed one of the main problems in electric vehicles carsharing which is location planning problem of recharging stations. An improved MIP model was optimized through branch-and-cut algorithm and genetic algorithm for the location planning problem of recharging stations. To

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Table 9. GA Results for path maximiziation; vehicle range=40 km, station capacity = 5

Budgetary Constraint	Location (number of SRS)	Location (number of FRS)	Location (number of BES)	Total number of stations (SRS, FRS, BES)	Path Covered	Number of Flows Covered (percent)
100,000.00	D3(2), D9(1), D10(1), D11(1)	-	S8(2), S4(2)	9 (5, 0, 4)	P3, P8, P11, P12	9 (29.0%)
200,000.00	D3(2), D9(1), D10(1), D11(1)	E(2)	S8(2), S4(2)	11 (5,2,4)	P2, P3, P4, P8, P11, P12	15 (48.4%)
250,000.00	D3(2), D9(1), D10(1), D11(1)	E(3)	S4(2), S8(2)	12(5,3,4)	P2, P3, P4, P8, P9, P11, P12	17(54.8%)
300,000.00	D3(2), D9(1), D10(1), D11(1)	E(4)	S4(2), S8(2)	13 (5, 4, 4)	P1, P2, P3, P4, P8, P9, P10, P11, P12	19 (61.3%)
400,000.00	D3(2), D5(1), D9(1), D10 (1), D11(1)	E(5)	S4(2), S8(2)	15 (6,5,4)	P1,P2, P3, P4, P8, P9, P10, P11, P12	22(71.0%)
500,000.00	D3(2), D4(1), D5(1), D6(1), D9(1), D10(1), D11(1), S7(1)	D(2), E(5)	S4(2), S8(3)	20 (8,7,5)	P1,P2, P3, P4, P6, P7, P8, P9, P10, P11, P12	28(90.3%)
548,000.00	D3(2), D4(1), D5(1), D9(1), D10(1), D11(1)	D(3), E(5)	S4(2), S8(4)	21 (7,8,6)	P1,P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12	31 (100%)

analyze the strengths, weaknesses, opportunities, and threats of the proposed approach, we conducted the SWOT analysis.

The results of SWOT analysis for location planning of recharging stations problem can be seen in Figure 6 below.

The main strength of this study is the comparison study which shows the competency between an exact method namely branch and cut and a heuristic method namely genetic algorithm. We also improved the model which led to better distribution of the recharging stations based on the users' real need.

Table 10. Approaches' results comparison

Results	Minimum Locating Cost ($)	Number of Installed Recharging Stations	Run Time
Initial Problem in Lingo Branch and Bound	978,000.00	84	less than 2 min, in some cases the time can be up to 60 min
Improved Problem in Barnch and Cut Algorithm	464,000.00	23	1.15 seconds
Improved Problem in Genetic Algorithm	548,000.00	21	9.43 min in average

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Figure 5. % Flow coverage for different methods

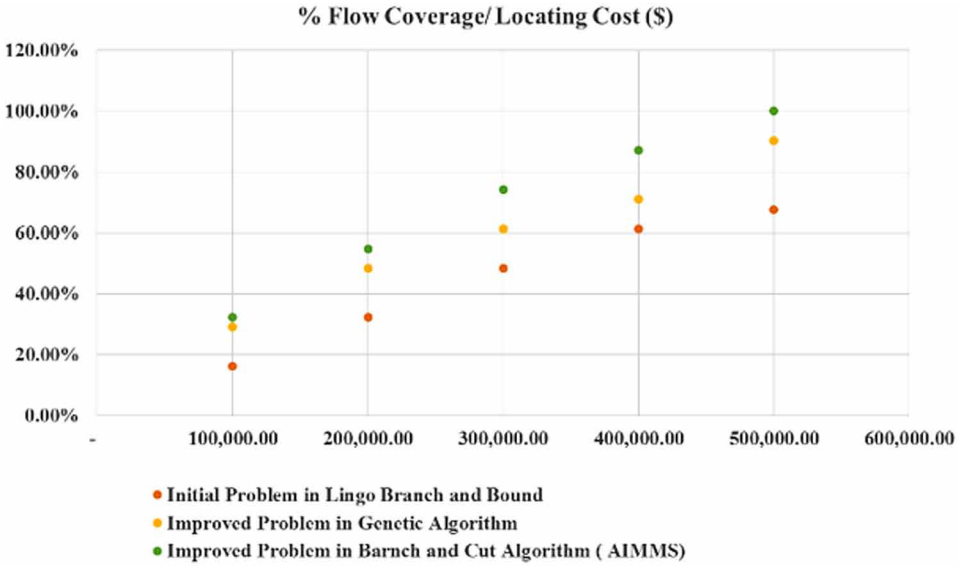

Figure 6. SWOT for recharging stations planning

S	W
Strengths	**Weaknesses**
• Improved model brings a wiser distribution of the charging stations based on the demand • Deducting the locating cost of the recharging stations installation to almost half of the initial achieved price through implementing the improved model in two different approaches	• There is not enough managerial studies to consider other limitations in the real-life such as the traffic volume in different nodes, population, climate and ergonomical effects and so on. • There should be more research studies to identify other types of electric vehicles recharging and considering them in the model which may lower the cost and bring more demand satisfaction
O	**T**
Opportunities	**Threats**
• Comparative study between two popularly used methods in optimization can be a strong base for the future studies in fleet management field • Due to the flexibility of the selected model for this study, the model can be adopted and implemented for so many other cases in other companies according to the results of this study	• While it is a very good idea to use the results of this study for other cases, there is the probability that with changing the type of optimization problem from MILP to other types like non-linear or quadratic programming, the performance results for the taken approaches changes due to different applications of the used methods • While this case study was a real project, in some case when the size of the projects increase enormously, there may be a change in the performance of the methods, so one should take this in to account when implementing for other cases

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FUTURE WORKS

There are much more heuristics methods which are of interest for solving MIP problems. Particle swarm optimization, ant colony optimization algorithm and tabu search are other heuristic algorithms that can be used. Also conducting case studies with large datasets and variables is a good practice to examine the performance of mentioned approaches in real life situations. One can perform more in-depth studies for comparing the performance of exact methods and approximate algorithm in these cases as well.

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Chapter 30
Supplier Selection in the Healthcare Sector:
A Multi-Criteria Proposal

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ABSTRACT

Supplier selection is a common practice in industrial sector and is usually conducted by engineers and administrators. However, in the healthcare sector, supplier selection is less commonly studied. This chapter proposes a methodology that simplifies the selection of suppliers in hospitals. As case study, the authors propose an example in which they evaluate six potential suppliers as alternatives with five attributes. The proposed methodology integrates the nominal group technique (NGT) to weight the attributes and dimensional analysis to estimate an index of similarity to an ideal supplier. This index of similarity is obtained from the best nominal values of the attributes. This methodology can be easily applied; it is intuitive and friendly to inexpert users, since the evaluation can be performed using a traditional

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spreadsheet. Also, the proposal allows for the simultaneous evaluation of multiple attributes and can be used by hospital administrators themselves, which prevents hospitals from hiring external services.

INTRODUCTION

In current globalized markets, final products are complex and diverse, since their components are usually processed in different countries, assembled in other a finally, distributed to customer in other. In such cases, supply chains play a crucial role in reducing costs, since in some special products, up to 70% of costs derive from its transport and logistics, where no value is added (Alikhani, Torabi, & Altay, 2019; Gosling, Purvis, & Naim, 2010). Under this scenario, hospitals establish their headquarters in strategic regions that allow them to reduce costs while still benefiting from a physical proximity to customers. Therefore, a potential location for a given hospital must always consider both the supply chain and suppliers' locations as important variables, as additional to customers for it service (Fu, 2019; Kim & Chai, 2017).

Every supply chain starts with the selection of its providers, who supply the necessary raw materials and services. Supplier for a hospital includes drugs supply, instruments and surgical equipment, cleaning and disinfection services, laundries, energy and other. Managers in hospitals must focus in integrate all those suppliers for offer a better health to customers and the relationship with them must be very close for reduce uncertainty (Imran, Kang, & Babar Ramzan, 2018).

Nowadays, many studies address the supplier selection process and identify the attributes that are to be considered, the techniques to be used, and the methodological procedures to be followed. In such works, we can successfully identify which activities and aspects must be taken into account when selecting suppliers in the industrial sector (Igarashi, de Boer, & Michelsen, 2015). Unfortunately, the healthcare sector is usually neglected, yet research has shown that clinics and hospitals struggle to appropriately select their suppliers. This problem aggravates when it compromises the health of patients (Hu & Dong, 2019; Qiaohai & Schwarz, 2011).

Currently there are several papers reporting the supplier selection problem and its importance for supplier chain in a company. For example, Yu, Shao, Wang, and Zhang (2019) report a case study using multicriteria techniques and integrate the sustainability concept for green supplier, Lo, Liou, Wang, and Tsai (2018) offer a method that integrates sustainability and green concepts, Su and Chen (2018) reports the case for uncertainty management in a supplier selection process, among others. It is easy to see that the sustainability in procurement is currently a constant.

Related to supplier evaluation and selection techniques, these can be simple or combined, depending on their complexity level, the technique is simple if there is used a unique technique or combined if two or more techniques are used. Also, they can be categorized into economic, analytic, and strategic techniques, being economic techniques and analytic techniques the most popular (Wetzstein, Hartmann, Benton jr, & Hohenstein, 2016). The economic techniques refer to traditional and common practice in industry and others sector and the most representatives are the internal rate of return (IRR), equivalent annual cost, payback return period, net present value, among others. These techniques are reductionist and exclude from the analysis qualitative information related to the alternatives and they are focused only to financial aspects (Grzybowska & Kovács, 2017).

The analytic techniques can integrate quantitative and qualitative information from alternatives and the most common techniques include the analytic hierarchy process (AHP), linear and integer programming,

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the technique for order of preference by similarity to ideal solution (TOPSIS), genetic algorithms and metaheuristic techniques, data envelopment analysis (DEA), and fuzzy logic, among others (Chai, Liu, & Ngai, 2013; Luan, Yao, Zhao, & Song, 2019). Such techniques have been popularly adopted to evaluate suppliers from an environmental perspective (Yazdani, Chatterjee, Zavadskas, & Hashemkhani Zolfani, 2017), based on innovation and adaptability attributes (Gupta & Barua, 2017), or to assess supply chain risk factors (Chen & Zou, 2017; Memari, Dargi, Akbari Jokar, Ahmad, & Abdul Rahim, 2019). All the aforementioned techniques are multi-criteria techniques, meaning that they can help evaluate multiple supplier attributes at the same time. However, in these techniques' evaluators must have knowledge of advanced mathematics and computation, yet hospital administrators usually lack such an academic background (Nguyen & Chen, 2018).

Finally, the strategic techniques refer to decision from managers that have a better knowledge about the mission, vision and strategic objectives. However, decision with these techniques has low acceptance by operators and low organizational levels (Jadidi, Cavalieri, & Zolfaghari, 2015).

Thus, to guarantee effective supplier evaluations, the healthcare sector tends to hire software and techniques experts, even though these experts are not familiarized enough with the needs of the hospital. External assistance thus entails increasing costs as a result of hiring external specialized services and adopting selection models that do not reflect the reality, usually because the external hired personnel does not know the entire selection problem (Awasthi, Grzybowska, Hussain, Chauhan, & Goyal, 2014).

To address the problem in the healthcare sector, this research proposes a multi-criteria methodology for supplier selection and evaluation that is user friendly and can be easily adopted by physicians and other hospital administrators at procurement departments. The use of this methodology could prevent clinics and hospitals from incurring additional expenses as a result of hiring external specialized services to use evaluation and selection software.

The remainder of this paper is organized as follows: Section 2 discusses a review of the literature on supply chain in the healthcare sector and summarizes the traditional supplier evaluation methodology. In Section 3 we propose our methodology that simplifies supplier evaluation, whereas Section 4 presents a case study to provide an example of how our approach can be utilized. Finally, Section 5 introduces the research conclusions and remarks for future work.

BACKGROUND

The Supply Chain in the Healthcare Sector

During the 1990s, experts in the healthcare sector started noticing the importance of the supply chain and how an appropriate supplier integration was key to its performance (Moynihan, 1997; Sarvestani, Zadeh, Seyfi, & Rasti-Barzoki, 2019). Also, they recognized the role of information and communication technologies (ICTs), since errors in this sector have a more serious impact than in the industrial sector and may put at risk the health and wellbeing of people (Brennan, 1998; Su & Chen, 2018). Similarly, during this decade, the concept on green supply chain in the healthcare sector emerged for the first time (Messelbeck & Whaley, 1999; Valipour Parkouhi, Safaei Ghadikolaei, & Fallah Lajimi, 2019), thereby contributing to the development of a series of indicators to supervise supply chain performance in terms of recycling and destruction of generated waste (Stoch, Ciecińska, Stoch, Kuterasiński, & Krakowiak, 2018).

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The concept of supply chain kept evolving throughout the years, and studies became more attentive to its critical success factors and activities that guarantee its success (Ansari, Kant, & Shankar, 2019). Over the years, research demonstrated that supplier participation, supply chain management, and managerial commitment were essential to ensure timely supply of medical products (Roark, 2005). Simultaneously, the literature began reporting success stories of hospitals that improved the tracking of medical products, and thus managed to simplify their decision-making processes, thanks to the use of new radio frequency identification technologies (RFID) (Acharyulu, 2007; Arya, Deshmukh, & Bhatnagar, 2015). Consequently, RFID along with other novel technologies were rapidly adopted by healthcare institutions across the globe, and their supply chains became the focus of interest to many researchers (Parker & DeLay, 2008) because lets to track important medicines, vaccines and human organs that require real time monitoring. In other words, the scientific community and healthcare experts acknowledged that the supply process deserved a lot of attention, since a shortage of medical products could entail serious problems. For this reason, supplier selection and a hospital's ability to maintain its institutional relationships have been current objects of study.

Other concepts related to the healthcare supply chain have emerged in recent years and have been associated with humanitarian logistics and disaster case management (Syahrir, Suparno, & Vanany, 2015; VanVactor, 2016), being the latter a matter of top priority in almost all nations. As a result, at least in Latin-American, supply chain management formally became an area of opportunity for improving services (Ketelhöhn & Sanz, 2016) and quality and increasing the financial performance of healthcare institutions (Kwon, Kim, & Martin, 2016; Tutuncu & Kucukusta, 2008).

Suppliers and Supplier Selection

Besides technologies, suppliers are another key component of the medical supply chain, since they play a crucial role in complying with norms and regulations and ensuring timely supply deliveries (Aggarwal, 2018; Malik, Abdallah, & Hussain, 2016). In the healthcare sector, suppliers can be defined as a company or a professional that provides the raw materials (drugs, utensils, materials, and equipment) and services necessary for a hospital or any other healthcare institution to offer uninterrupted health care services (Arya et al., 2015; Sunil Kumar & Routroy, 2018).

It is well known that hospital administrators and people responsible for supplying dispensed medications struggle to select the most appropriate suppliers. Fortunately, proposals such as De Boer's (de Boer, Labro, & Morlacchi, 2001; de Boer, van der Wegen, & Telgen, 1998) methodology support supplier selection and evaluation processes, making ease the job for managers, and de Boer et al. (1998) proposed four stages to successful supplier selection – defining the problem, identifying the supplier attributes to be assessed, evaluating a series of suppliers using a particular technique, and selecting the most suitable supplier. Three year later, de Boer et al. (2001) in a literature review related to techniques and methods used for supplier selection, conclude that those stages are constant in every case analyzed. This four-stage based methodology is popular in the industrial sector, and many studies referring to it discuss the various aspects of supplier selection and evaluation, such as the most common techniques (de Boer et al., 2001; de Boer et al., 1998), the impact of flexibility (Arabsheybani, Paydar, & Safaei, 2018; Gosling et al., 2010), and the impact of innovation attributes (Malik et al., 2016). A resumed description of Boer's methodology is presented below (de Boer et al., 2001; de Boer et al., 1998):

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Identifying the Problem

Some authors claim that this stage is commonly neglected, as hospital administrators can mistakenly jump up to the last stage (Kellner & Utz, 2019; Wetzstein et al., 2016). Identifying the problem is so important, because it implies researching and listing potential suppliers, as only a few of the many available providers can actually meet the hospital's demands (Keshavarz Ghorabaee, Zavadskas, Amiri, & Esmaeili, 2016; G. K. kumar, Rao, & Rao, 2018). At this stage, hospital administrators should perform the following tasks:

- Identify the quantity of material to be purchased, because sometimes the suppliers have a minimum purchase required for delivery (Gurel, Acar, Onden, & Gumus, 2015; Lo et al., 2018).
- Determine the product lifecycle: Amid the rapid advance of new technologies, a given medical product may be rapidly replaced by another one (Hamdan & Cheaitou, 2017; Rezaei, Nispeling, Sarkis, & Tavasszy, 2016).
- Identify suppliers who are influential in the geographical area. This improves the selection of potential suppliers (Luthra, Govindan, Kannan, Mangla, & Garg, 2017; Manerba & Perboli, 2019).
- Always find out whether the hospital can replace a brand-named pharmaceutical drug by its generic or similar drug as low-cost alternatives, fast delivery and quality or purity (Yu et al., 2019).
- If the hospital has one supplier only, always perform uncertainty and risks analyses to avoid running out of a medical product or service (Bohner & Minner, 2017; Chen & Zou, 2017).
- When possible, sign work a contract with every supplier to ensure formal relationships between both parties. Contracts help assign and delimitate responsibilities (Chen & Zou, 2017).
- Finally, assess the suppliers' commitment to the environment and their job stability levels (Gurel et al., 2015).

Determining the Supplier Attributes to be Evaluated

Studies addressing supplier evaluation and selection have managed to identify a wide range of supplier attributes, whose importance depends on the problem to be solved. Generally, supplier attributes are categorized in two groups: tangible or quantitative attributes and intangible or qualitative attributes. The former can be represented using metrics such as a drug's cost or the equipment's engineering and technical characteristics. On the other hand, intangible or qualitative attributes are normally represented thanks to experts' assessments or opinions. Two qualitative attributes include after-sales service and order risks (Keshavarz Ghorabaee et al., 2016).

Procurement administrators in healthcare institutions must keep in mind that criteria for selecting a supplier may be challenging to assess, since gaining one attribute often means losing another one. For instance, there is a strong relationship among equipment quality, precision, and cost (Ho, Xu, & Dey, 2010), as the higher the quality and the precision of a machine, the higher its price. In other words, looking for a piece of equipment that achieves the maximum quality and precision, often entails higher expenses.

In their work, Ho et al. (2010) conducted a review of the literature on supplier attributes and found out that quality, expressed in different metrics, was the most prominent (68 references). It was then followed by delivery times (64), costs (63), production capacity (39), after-sales service quality (35), use of new technologies (25), research and development capacity (24), financial support and performance (18), reputation and prestige (15), and environmental commitment (3). Also, other studies have reported

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supplier attributes such as education and training, appropriate packaging and delivery, labor disputes history, conflict resolution skills, reputation and ranking, economic performance history, claim policies and warrants, vendor-buyer communication, and corporate image and impression, among others (Chai et al., 2013; de Boer et al., 2001; Govindan, Rajendran, Sarkis, & Murugesan, 2015; Ho et al., 2010; Igarashi, de Boer, & Fet, 2013; D. Kumar & Rahman, 2015; Simić, Kovačević, Svirčević, & Simić, 2017). For a complete review of supplier attributes, please consult Govindan et al. (2015) and Wetzstein et al. (2016) and for specific green attributes, please refers to Mendoza-Fong, García-Alcaraz, Díaz-Reza, Jiménez-Macías, and Blanco-Fernández (2019), Jose Roberto Mendoza, Jorge Luis, Aidé Aracely, Cuauhtémoc Sánchez, and Valeria Martínez (2017) and Villanueva-Ponce et al. (2015).

Finally, it is important to keep in mind that every hospital has different needs and thus expectations with respect to a supplier; therefore, the attributes to be considered, as well as their importance, may significantly vary depending on the context (Govindan et al., 2015). Moreover, note that some attributes must be evaluated through subjective assessments.

Evaluating Suppliers Using a Particular Technique

The next step after identifying the supplier attributes to be assessed is to arrange them hierarchically. To make this arrangement, experts recommend using techniques that assign each attribute an index. In this sense, Chai et al. (2013) conducted a systematic review of common decision techniques, whereas Igarashi et al. (2013) identified some of the attributes and techniques for green supplier evaluation. Similarly, Govindan et al. (2015) reviewed a series of multi-criteria techniques for green supplier selection, thereby combining the goals of the two aforementioned studies. However, Wetzstein et al. (2016) conducted one of the most comprehensive state-of-the-art reviews for the supplier selection problem, and the author subsequently proposed future trends in this activity. Finally, Simić et al. (2017) reviewed the use of fuzzy-logic to solve problems related to supplier selection within the last 50 years. In general, the goal of all multi-criteria techniques is to propose an ordered list of alternatives with respect to an evaluation index generated using multiple algorithms (Govindan et al., 2015).

Selecting a Supplier

Considering the generated index, decision groups must select one of the alternatives (Chai et al., 2013). At this stage, it is important to follow these suggestions:

- Determine whether a product or service will be provided by one supplier only.
- Propose the alternative to senior hospital managers, since they know the hospital's strategic plans.
- Reach the chosen suppliers as soon as possible to formalize the relationship and discuss contract clauses.

METHODOLOGY AND CASE STUDY

This section first discusses the steps followed to develop our supplier selection methodology. In this sense, we adopted of Gurel et al. (2015) generic proposal, who in turn followed de Boer et al. (2001)'s four stages to supplier selection. Then, we propose a case study to exemplify its application.

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Defining the Problem

A hospital needs to replace the old infant radiant warmers at its pediatrics unit with more modern equipment. The problem with their radiant warmers is that they have been used for more than 10 years and have been the source of many errors. Moreover, new alternatives available in the market include a wider range of functions and sensors that allow nurses and doctors to monitor the health of newborns more efficiently and reduce risk in healthcare.

For this case study, the hospital administrator gathered a decision-making group of four experts to evaluate and select the most suitable supplier(s). These group members were named E_1, E_2, E_3, and E_4 and represent to general manager as decision making leader, the finances manager, nursing manager and neonatology director because they represent the most important departments associated to this decision. The general manager knows the strategy for the hospital, the finances manager knows the economic resources available and the possible financial plans, the nursing manager knows the technical specifications for the new infant radiant warmers requested and the neonatology knows the importance of monitoring the newborns.

The group leader tracked the potential alternatives (suppliers) to be evaluated and use some references from internet and the experience reported from other hospitals. Then, the team concluded that only six suppliers had a significant influence around the hospital's location and could supply the required radiant warmers and can guarantee technical support in a fast way in case of mistakes or problems. Potential suppliers were named S^1, S^2, S^3, S^4, S^5, and S^6.

Attributes

The decision-making group considered five attributes to evaluate in the suppliers, three quantitative and two qualitative. These attributes are listed below:

Costs (CO, $). It refers to the hospital's financial outlay and is expressed in US dollars. It is a quantitative attribute to be minimized.

Weight (WE, Kg). It refers to an infant radiant warmer's weight, expressed in kilograms. It is a quantitative attribute to be minimized to facilitate the handling of equipment by nurses and personnel in the hospital.

Integrated functions (IF, #). It refers to the number of functions integrated as sensors that allow nurses and doctors to monitor a newborn's health more efficiently and in real time. This quantitative attribute is expressed using a real number and should be maximized because that mean more information for personnel.

Quality service (QS). It refers to the quality of the after-sales service. In this case study, this qualitative attribute holds significant importance, since nurses and doctors may need further training in and assistance with the new equipment. More specifically, *QS* assessed the supplier's ability to offer rapid and good equipment maintenance services. It is an attribute to be maximized.

Reliability (RE). Because hospitals need reliable information with little variability and in real time, this attribute assesses the sensors' reliability, and thus the supplier's trustworthiness. This is a qualitative attribute that should be maximized.

To assess the quantitative attributes, the group reviewed the technical attributes of each alternative that is reported by salesmen. As for the subjective attributes, the group members assessed them on a

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1-9 scale, where 1 implied that an alternative always lacked a given attribute, and 9 indicated that an alternative always had a given attribute.

Evaluating Alternatives

Currently there are several techniques for supplier selection; however, this case study in a hospital requires easy techniques, because some of them are difficult to understand for manager and doctors that have not advanced knowledge related to mathematics or programming. The supplier evaluation was performed using two techniques: the nominal group technique (NGT) and dimensional analysis. The NGT was used to weight all the attributes and obtain the assessments of the subjective attributes because it is easy to use, integrates the decision making group and was used previously by the expert an reported in hospitals by Kelz, Sellers, Merkow, Aggarwal, and Ko (2019). Whereas dimensional analysis allowed the group to compare the six potential suppliers to an ideal supplier and can be performed using a single spreadsheet as reported by Braglia and Gabbrielli (2000) and recently by García Alcaraz, Alvarado Iniesta, and Maldonado Macías (2013).

Dimensional analysis compares every alternative to an ideal supplier that is generated using the best nominal values of the attributes and generates a similarity index. Logically, the best supplier must be very similar to the ideal and hypothetical alternative.

The following sections thoroughly discuss the two techniques.

A Matrix Approach to Decision-Making and the Nominal Group Technique

To understand our proposed methodology, suppose that there are J objective or quantitative attributes and L subjective or qualitative attributes being evaluated in a total of k suppliers. Therefore, objective attributes are $X_1, X_2, \ldots X_J$, whereas subjective attributes are $X_{J+1}, X_{J+2}, \ldots X_{J+L}$. In this study, the matrix approach to decision-making took as its basis Rudnik and Kacprzak (2017) approach.

As previously mentioned, the values of the objective attributes were obtained from the technical files provided by the suppliers. These values were represented in a matrix of objective values (**OV**) using equation 1. On the other hand, the values of the subjective attributes were obtained from the group members' assessments. Here we used the NGT, as every group member constructed his/her own matrix as shown in equation 2.

$$OV = \begin{matrix} S^1 \\ S^2 \\ \vdots \\ S^k \end{matrix} \begin{bmatrix} X_1^1 & X_2^1 & \ldots & X_J^1 \\ X_1^2 & X_2^2 & \ldots & X_J^2 \\ \vdots & \vdots & \ldots & \vdots \\ X_1^k & X_2^k & \ldots & X_J^k \end{bmatrix} \quad (1)$$

where:

X_j^k = value of attribute j in supplier k

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j= 1, 2…J
k= 1..... K

$$SV^{p} = \begin{matrix} S^1 \\ S^2 \\ \vdots \\ S^k \end{matrix} \begin{bmatrix} X_{J+1}^{1P} & X_{J+2}^{1P} & \ldots & X_{J+L}^{1P} \\ X_{J+1}^{2P} & X_{J+2}^{2P} & \ldots & X_{J+L}^{2P} \\ \vdots & \vdots & \ldots & \vdots \\ X_{J+1}^{KP} & X_{J+2}^{KP} & \ldots & X_{J+L}^{KP} \end{bmatrix} \quad (2)$$

where:

x_{J+i}^{k} assessment from expert P on supplier PR^k with respect to attribute X_{J+i}
k=1,... k
i=1,...L

Equation 2 represents only the opinions of a single group member or decision-maker with respect to the five attributes. Thus, equation 3 shown below helped us integrate all the assessments from all group-members. This equation estimated the arithmetic means of the experts' assessments. This new matrix is known as matrix of total subjective values (**TSV**).

$$TSV = \sum_{P=1}^{P} SV^{P} \,/\, P = \begin{matrix} S^1 \\ S^2 \\ \vdots \\ S^k \end{matrix} \begin{bmatrix} X_{J+1}^{1} & X_{J+2}^{1} & \ldots & X_{J+L}^{1} \\ X_{J+1}^{2} & X_{J+2}^{2} & \ldots & X_{J+L}^{2} \\ \vdots & \vdots & \ldots & \vdots \\ X_{J+1}^{K} & X_{J+2}^{K} & \ldots & X_{J+L}^{K} \end{bmatrix} \quad (3)$$

where:

$x_{J+i}^{k} = \dfrac{\sum_{p=1}^{P} x_{J+i}^{kp}}{P}$ is the average experts' assessment for supplier PR^k with respect to attribute X_{J+i}.
k=1,... k
i=1,...L

Here is important to mention that some time the one expert has not enough information for make an assessment and then he does not assign a value. In this case, value is not zero, and P represent the experts that really evaluate the attribute or give an assessment for it.

Once objective and subjective attributes were estimated, they were integrated into a single matrix as shown in equation 4. This matrix is known as final decision matrix (**FDMM**) and is at the core of many multi-criteria decision techniques, and in this case, J=3 because there are three objective attributes and L=2 because there are two subjective attributes.

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$$FDMM = \left[OV, TSV\right] = \begin{matrix} S^1 \\ S^2 \\ \vdots \\ S^k \end{matrix} \begin{bmatrix} x_1^1 & \dots & x_J^1 & x_{J+1}^1 & \dots & x_{J+L}^1 \\ x_1^2 & \dots & x_J^2 & x_{J+1}^2 & \dots & x_{J+L}^2 \\ \vdots & \dots & \vdots & \vdots & \dots & \vdots \\ x_1^K & \dots & x_J^K & x_{J+1}^K & \dots & x_{J+L}^K \end{bmatrix} \quad (4)$$

Dimensional Analysis

In their research, Braglia and Gabbrielli (2000) used dimensional analysis to select a series of robots. The technique was easy to use with spreadsheets and showed greater robustness in comparison with other techniques, which is why we decided to adopt it for this case study. Every row in the **FDMM** represented a supplier considered as a *J+L* point in the dimensional Euclidean space, as shown in equation 5. Dimensional analysis assumes there is an ideal supplier whose characteristics are the best nominal values (X^+) of every attribute or column in the **FDMM**. This is why it is important to know the direction or preference for every attribute, if they are to be maximized or minimized. An ideal supplier is hypothetical, since it really does not exist. It is represented using equation 6 below:

$$PR^k = (x_i^k \text{ .....} x_{J+L}{}^k) \text{ for } k = 1,2, \text{ …..k} \quad (5)$$

$$IS = (x_1{}^+, x_2{}^+, \text{.....} x_{J+L}{}^+) \quad (6)$$

where:

PR^k represent an supplier or alternative nin evaluation
IS is the ideal solution or ideal supplier

Dimensional analysis compares every alternative in the **FDMM**, represented by S_i, with the ideal alternative or supplier (*IS*). Then, it generates a similarity index (*SI*) using equation 7.

$$SI = \sqrt[W]{\prod_{i=1}^{J+L} \left[\frac{X_i^k}{IS_i}\right]^{w_i}} \quad (7)$$

where:

SI: similarity index
S_i: standard or ideal value for attribute *i*
X_i^k : value of supplier *k* for attribute *i*.
w: weight or importance level of attribute *i*

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Nominal Group Technique

Attributes can be expressed in different units and a traditional sum cannot be applied, but when dividing X^k_i by the value of *IS*, the result obtained is an dimensionless value and then the values can be added. Also, because the level of importance of a given attribute may vary across group members, it is important to calculate this value, represented by w_i, for every attribute. In equation 7, *W* stands for the sum of the absolute values of the weights and is calculated using equation (8).

$$W = \left| \sum_{i=1}^{J+L} w_i \right| \tag{8}$$

Dimensional analysis considers the impact of attributes on their environment; therefore, attributes to be minimized – such as costs – must have a negative w_i value, whereas the attributes to be maximized – such as integrated functions – must have a positive w_i value.

This model, for simplicity reasons, used the NGT to generate the importance level of attributes. Thus, decision-makers rated the level of significance of every attribute on scale of 1 to 9, where 1 indicated that an attribute was not important, and 9 indicated that an attribute was extremely important. Then, equation 9 helped us to calculate the average assessment or value of every attribute, considering the number of experts who performed the assessments.

$$w_i = \frac{\sum_{R=1}^{P} O_{iR}}{P} \text{ for R=1, 2, …P and i=1,2,….J+L} \tag{9}$$

where:

O_{iR}= assessment from expert *R* on attribute *i*
w_i= weight of attribute *i*
P= number of experts
J= the number of objective attributes
L= the number of subjective attributes

Selecting an Alternative

Dimensional analysis generates a similarity index (*SI*) ranging from 0 to 1 with respect to an ideal solution or alternative (*IS*). In our case study, 0 implied that an evaluated supplier lacked all the characteristics of an ideal supplier (not similar), whereas 1 indicated that an evaluated supplier possessed has all the characteristics of an ideal supplier (100% of similarities) and could be considered a dominant alternative; however, that situation is not often. For instance, a supplier showing $SI = 0.851$ was 85.1% similar to an ideal supplier. In this sense, dimensional analysis always looks for the alternative with the highest *SI* to the ideal solution or *IS*.

Once the best alternative is selected, we suggest performing the following tasks:

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Table 1. Values of objective attributes

S^i	CO ($)	WE (Kg)	IF (#)
S^1	6280	72	45
S^2	4595	78	40
S^3	5940	69	46
S^4	7099	68	38
S^5	6425	70	42
S^6	6930	69	43

Source: Authors

1. Analyze whether it is convenient to rely on a single supplier. Sometimes is better to have two suppliers.
2. Analyze the variation of *SI* across suppliers, because sometimes the differences among them are very similar.
3. Modify the importance level attributes to perform a sensitivity analysis and test the robustness of the solution; in other words, change the values for w_i.

CASE STUDY EVALUATION

In this case study, a hospital needed to replace the infant radian warmers of its pediatrics unit. At the second stage of the selection process, the decision group – formed by four experts – identified six potential suppliers to be evaluated through five attributes. Information presented in this section belongs to real suppliers, which is why we codified them to protect their privacy.

Objective Attributes

Table 1 shows the values of the objective attributes for each alternative; every row represents a supplier, and every column represents an objective attribute. For instance, Table 1 indicates that S^1 offers a radiant warmer costing 6,280 US dollars, weighting 72 kilograms, and having 45 integrated functions that allow doctors and nurses to monitor newborns more efficiently. Similar interpretations can be elaborated for the remaining suppliers.

Subjective Attributes

Table 2 introduces the calculation of the values for the two subjective attributes – quality service (QS) and reliability (RE). The table includes the assessments that every decision-maker or expert made for each subjective attribute. As previously mentioned, subjective attributes represented the $\mathbf{SV^p}$ matrix from equation 2. The last two columns of the table include the average values estimated using the equation 3. These values represented the **TSV** matrix and were later included in the **FDMM**.

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Table 2. Values of subjective attributes

S	Expert								Average *(TSV)*	
	E1 (SV^1)		E2 *(SV^2)*		E3 *(SV^3)*		E4 *(SV^4)*			
	QS	RE	QS	RE	QS	RE	QS	RE	QS	RE
S^1	7	8	9	9	8	9	7	6	7.75	8
S^2	9	8	6	7	8	6	7	5	7.5	6.5
S^3	6	8	7	9	8	6	8	7	7.25	7.5
S^4	7	8	6	9	8	7	5	8	6.5	8
S^5	6	8	7	9	8	7	8	9	7.25	8.25
S^6	9	6	8	7	9	8	7	6	8.25	6.75

Source: Authors

Final Decision Matrix

After integrating the matrix of objective values and the matrix of subjective values into a single matrix, we obtained the final decision matrix (**FDMM**) shown in Table 3. The penultimate row specifies the attributes' directions, so we could generate the ideal alternative or supplier (max for maximum and min for minimum). This ideal supplier is included in the last row in Table 3 and was used to compare the six alternatives. Based on such data, we concluded that the ideal supplier to the hospital would have the cost attribute of S^2, the weight attribute of S^4, the integrated functions attribute of S^3, the after-sales service attribute of S^6, and the reliability attribute of S^5. In other words, the ideal supplier would sell radiant warmers weighting only 68 kg and having 46 integrated functions for $4,595 USD, but also, this supplier should need to score 8.25 in attributes after-sales service and reliability. As can be seen, the ideal attribute scores are not contained in a same supplier, because they come from all them. This would challenge the selection process if the hospital decided to consider only one attribute.

Importance Levels of Attributes: Weighting

Usually, attributes encompassed in an evaluation differ in significance. For this case study, Table 4 shows the experts' (decision-makers) assessments regarding each attribute in a scale from 1 to 9. The penultimate row indicates the average assessment values of attributes, and the last row indicates their impact – either negative or positive. According to the experts, compliance with attribute Integrated Functions (*IF*) is the most important when selecting a supplier, since it shows an average value of 8. This result is consistent with the hospital's problem, since the lack of modern functions in its radiant warmers is one of the reasons why administrators decided to invest in new ones. The second most important attribute seemed to be the sensors' reliability (*RE*) (average = 7.8). On the other hand, costs appeared as the least important attribute (average = 6.4), which highlights the hospital's priorities toward customers and security in newborns.

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Table 3. Final decision matrix

S^i	CO	WE	IF	QS	RE
S^1	6280	72	45	7.75	8
S^2	4595	78	40	7.5	6.5
S^3	5940	69	46	7.25	7.5
S^4	7099	68	38	6.5	8
S^5	6425	70	42	7.25	8.25
S^6	6930	69	43	8.25	6.75
Direction	Min	Min	Max	Max	Max
IS	4595	68	46	8.25	8.25

Source: Authors

Estimating the Similarity Index

To estimate the similarity index, we used equation 7. Our results are introduced by Table 5, where values were rounded up to four decimal places. When crossing out each supplier (row) with its attributes (columns) we obtained the weighted coefficients of the attributes' values. The penultimate column in the table includes the similarity index (*IS*) generated when comparing every supplier, through all its attributes, with the ideal alternative. As for the final column, it provides each supplier with a ranking number considering the *IS* value.

Note that all the attributes showed the ideal value (1) once, which confirms they are all part of an ideal alternative. Similarly, suppliers S^2, S^3, S^4, S^5, and S^6 possessed an attribute with the ideal value, whereas the attributes in supplier S^1 do not reach this value. Still, S^1 has the highest index of similarity to the ideal supplier (SI = 0.9136) that indicates that is 91.36% similar to that ideal solution. In this sense, equation 10 below shows the preference order of suppliers, where S^1 is preferred over S^3, which in turn is preferred over S^5, which in turn is preferred over S^2, which in turn is preferred over S^6. Finally, S^4 seems to be the least suitable supplier, considering the hospital's needs.

$$S^1 \succ S^3 \succ S^5 \succ S^1 \succ S^2 \succ S^6 \succ S^4 \quad (10)$$

Table 4. Level of importance of attributes

EXPERT	*CO*	*WE*	*IF*	*QS*	*RE*
E_1	8	7	9	6	7
E_2	5	6	7	7	9
E_3	7	5	7	9	8
E_4	6	7	8	5	8
E_5	6	8	9	7	7
Average	6.40	6.60	8.00	6.80	7.80
w_i	-6.4	-6.6	8	6.8	7.8

Source: Authors

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Table 5. Similarity index estimation

S^i	CO	WE	IF	QS	RE	SI	Rank
S^1	0.1354	0.6857	0.8388	0.6537	0.7866	0.9136	1
S^2	1.0000	0.4043	0.3269	0.5230	0.1557	0.8805	4
S^3	0.1934	0.9081	1.0000	0.4153	0.4755	0.9099	2
S^4	0.0618	1.0000	0.2169	0.1977	0.7866	0.8408	6
S^5	0.1170	0.8259	0.4830	0.4153	1.0000	0.8952	3
S^6	0.0721	0.9081	0.5830	1.0000	0.2090	0.8731	5

Source: Authors

Note that the similarity indices of S^1 and S^3 were considerably close ($SI = 0.9136$ vs $SI = 0.9099$). To find such a small difference, we had to round values up to four decimal places; otherwise, both alternatives were tied up. This technique allowed the hospital to be more flexible when choosing the most appropriate supplier.

DISCUSSION

Supplier selection is a complex problem involving the assessment of multiple alternatives with important attributes or characteristics. Preferably, a decision like this should be the responsibility of decision-groups for get a better consensus among that group. This article proposes a new methodology to streamline the supplier selection process in the healthcare sector, applying the case study to warmers for newborns. Our case study evaluated six alternatives or potential suppliers though five attributes. To simplify the task, we proposed the use of a regular spreadsheet to perform the evaluation. According to our results, we propose the following conclusions:

- Our proposed methodology uses dimensional analysis, an intuitive, multi-criteria technique that generates a similarity index. The hospital administrators (decision-makers) involved in this case study easily learned to use this technique because has an intuitive perspective regarding the ideal solution.
- Our NGT-based approach to assess the importance level (weight) for each attribute ensures democratic decision-making, since this technique incorporates the opinions of all the decision-makers and guarantee consensus.
- In this methodology, we suggest using regular spreadsheets to perform the supplier selection analysis. This implies that experts and hospital administrators do not need to acquire any specialized software or hire external expert assistance and incurring in additional cost, and every decision maker are familiarized with spreadsheets.
- Dimensional analysis has proven to be a robust technique in comparison with other multi-criteria techniques Braglia and Gabbrielli (2000), which increases the reliability of our methodology.
- As a limitation, our methodology was only tested in one hospital with one particular decision group, yet other medical institutions may have different needs according to their own environment and customers. The underlying implication of this is that we may obtain different results if the methodology is tested in other scenarios.

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FUTURE RESEARCH DIRECTIONS

Multi-criteria decision-making techniques are easy to apply and are currently integrated into many software. However, knowledge is required to understand them, and doctors and hospital managers do not have enough time to do so. For this reason, in future research, future works on friendly software development is required and preferably, it must be integrated into programs that they already manage and have frequently use, such as in Excel.

In the same way, future research will seek to identify the attributes that are necessary for the evaluation process of drug suppliers and not only for technology providers, because drugs are vital for hospitals. Also, managers are asking for possibilities to apply this methodology in human resource selection, then attributes for personnel in hospitals are required.

CONCLUSION

Supplier selection is a complex problem and every hospital has their own requirements and it's not easy to declare a universal methodology and attributes to be evaluated; however, manager must follow general task to evaluate them. Manager and the decision-making group must integrate their own experiences in the evaluation process by assessments in subjective attributes.

Dimensional analysis is a technique that has proved efficiency and robustness y supplier evaluation process, has an intuitive understanding based on ideal solution, it was integrated in excel, and manager no need to pay expert persons in multicriteria decision. This facilitate the decision process and integrates the real feeling and experience from managers and hospital administrators.

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KEY TERMS AND DEFINITIONS

Alternative: Represents a possible solution to a selection problem in a multicriteria decision making.

Attribute: Refers to a quality or feature regarded as a characteristic or inherent part of someone or something.

Decision Group: Set of persons that are experts and are responsible for decision making in a company. Usually, they are expert in decision making techniques to facilitate this process.

Dimensional Analysis: A multi-attribute and multicriteria decision making technique that compares real alternatives again an ideal solution and let to use weights for different attributes.

Healthcare: Refers to the maintenance or improvement of health via the prevention, diagnosis, and treatment of disease, illness, injury, and other physical and mental impairments in human beings.

Manager: Represents a person that is responsible for decision making process in a business or industry. A manager usually request support from experts in several areas.

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Multiple-Criteria Decision Analysis: It is a sub-discipline of operations research that explicitly evaluates multiple conflicting criteria in decision making (both in daily life and in settings such as business, government and medicine). Usually a criterion is integrated by several attributes or characteristics.

Selection Problem: This problem appears when several alternatives and attributes are evaluated a only one of them must be selected.

Supplier: Refers to a person, company, or organization that sells or supplies something such as goods or equipment.

Supply Chain: Refers to a system of organizations, people, activities, information, and resources involved in moving a product or service from supplier to customer. The activities involved the transformation of natural resources, raw materials, and components into a finished product that is delivered to the end customer.

Weight: represents the level of importance for an attribute in a multicriteria decision-making process. The sum of weights for attributes must be 100% or 1.

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