Research Essentials

Hierarchical Planning and Information Sharing Techniques in Supply Chain Management

Atour Taghipour

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Hierarchical Planning and Information Sharing Techniques in Supply Chain Management

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case, the vehicle routing problem with deliveries and pickups of goods is an extension of vehicle routing problem in which goods are transported from a depot (or multiple depots) to customers, as well from customers to the depots. There is tremendous work in the literature of this problem. Freight transport management deals with all distribution problems along the supply chain. This chapter presents a comprehensive review and survey of this literature. The literature is classified into four fundamental classes according to the way of the customers' visit and methods used for solving. Then different variants are generated according to the elements of the proposed framework. During this chapter, based on a proposed framework, the authors analyze the literature of the vehicle routing problem with deliveries and pickups, and as a result, the researchers propose a new classification where they give a short modeling of it.

This chapter focuses on the hierarchical planning and execution for supply chain management in public healthcare services. The authors first introduce tiered organizational and services delivery structure of public healthcare services followed by various supply chain issues that public healthcare services encounters. They then review hierarchical planning and execution discussions for the strategic, tactical, and operational decisions in supply chain literature. They continue the discussion with public healthcare services cases on medicine and equipment maintenance supply chains. They compare hierarchical planning execution discussions in supply chain management literature vis-a-vis healthcare services cases. Their main argument is that much can be gained by the public healthcare services by striving for reduced information asymmetry and employing appropriate functional aggregation at various levels of the hierarchically organized public healthcare supply chains.

Organizations adopt many strategies to gain competitive advantage. An important strategy is adopting green practices. Cost-benefit and customer value enhancement are two other strategies. By combining all of these elements, organizations can acquire a superior competitive advantage. There are contradictory findings on applying the cost-benefit element to green supply chain management (GSCM) and no clear theory on how to combine these elements to gain a competitive advantage. The primary objective of this study is to identify the impact of GSCM on competitive advantage of business organizations in Sri Lanka. Sample technique used was convenience sampling method. Data was collected from 30 organizations that were following green practices in Sri Lanka. The data were analyzed using descriptive analysis, correlation coefficient, and simple regression model. The results show that there is a strong positive relationship between GSCM and competitive advantage, and rather than applying just one element to gain a competitive advantage, it was considered more effective to apply both cost-benefit and customer value enhancement simultaneously.

Supply chain management (SCM) is essentially a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time in order to minimize system-wide costs or maximize profits while satisfying service level requirements. To solve complex problems in SCM and to obtain optimization, various meta-heuristics algorithms can be used. Thus, this chapter discusses the background of meta-heuristics algorithms. The related work and future research direction for using meta-heuristics approaches for supply chain management are addressed in this chapter.

This chapter introduces the impact of competitive strategy on strategic supply chain network design decisions. The aim of increasing competitive advantage forces firms to deal with multiple conflicting objectives. Since supply chains are affiliate networks including multiple parties, accomplishing a solitary objective corresponds to an inadequate effort to maintain the sustainability of supply chain. The overall integrity and sustainability of the supply chain can be provided by satisfying the expectations of each parties. The loyalty in the supply chain is achieved by offering distinguished service among suppliers and customers rather than delivering almost same services. This can only be achieved through network design models by taking into account multiple conflicting objectives. The firm's competitive strategy defines a particular set of objectives to achieve specific goals on these performance attributes. This chapter examines the main problem domains in SC design, strategic performance measures, and recent literature on single/multiple objective models.

Foreword

This book examines the concept of Hierarchical Planning and Information Sharing Techniques in Supply Chain Management, which is a new management trend among academics and practitioners. Despite this, there is a scarcity of books covering the topic of supply chain planning, this book fills a major gap in hierarchical planning and information sharing Techniques. More importantly, I have been very impressed with the comprehensive treatment of this topic in this book.

The book analyzes, the concept of hierarchical supply chain planning from different aspects. The book deals with different topics in the domain such as: anticipation of demand, hierarchical planning in the service sector, meta-heuristics technics, sustainability, distribution, reverse logistics, decision analysis and dynamic systems.

The parts of the book are well-linked and integrated altogether and offer a holistic and overarching perspective of supply chain planning. Hence, readers of this book will benefit extensively by this approach and the intertwined theoretical and applied approach followed when covering various aspects of planning.

I am confident that this book will be very popular amongst academics and practitioners. In addition, it will be extremely valuable to both undergraduate and postgraduate students reading for Supply Chain Management. To conclude, this book is a welcome addition. I recommend it highly to anybody interested to the topic of Hierarchical Planning and Information Sharing Techniques in Supply Chain Management.

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Preface

AN OVERVIEW OF THE HIERARCHICAL PLANNING AND INFORMATION SHARING TECHNIQUES IN SUPPLY CHAIN MANAGEMENT

Supply chains are networks of organizations that create and deliver value in the form of products or services to the final consumer through upstream and downstream linkages (Christopher, 1998). In fact, this definition also includes the internal networks of business units of integrated companies (Halal, 1994; de Kok & Fransoo, 2004). Therefore, supply chains are characterized by distinct, yet mutually interdependent decision domains with independent business objectives (Simchi-Levi et al., 2000), as well as by an asymmetrical distribution of information. In this context, the lack of decisional, organizational and informational integration leads to inefficiencies related to poor coordination of production and distribution decisions, such as the bullwhip effect (Lee et al., 1997), which result in missed opportunities, delays, inefficient inventory decisions, poor capacity allocation and misuse of resources, all leading to increased cost. In order to improve supply chain coordination, companies have developed collaborative practices across different functions of the supply chain (Simatupang & Sridharan 2002), and academics from several disciplines have proposed a number of coordination methods.

A DESCRIPTION OF THE TOPIC IN THE WORLD TODAY

Initiated by Hax and Meal (1975), one of the first attempts to address the coordination of operations planning of supply chains involves simplifying complex decision problems into a hierarchy of mutually inter-dependent decision problems. These approaches try to decompose the overall decision problem into a hierarchy problem and sub-problems linked by master/slave relationship. Here, coordination is carried out in a cascade process from long term to short term decisions, or from customer to suppliers. This decomposition leads to simpler and interdependent planning functions. The most significant characteristic of these approaches is the use of greedy/one-way information exchange.

A DESCRIPTION OF THE TARGET AUDIENCE

Hierarchical Planning and Information Sharing Techniques in Supply Chain Management is the application of hierarchical planning techniques to all major functional areas of supply chain planning, including planning & forecasting, production, inventory management, distribution & transportation. In particular, the book provides a comprehensive review and understanding of how hierarchical planning techniques and principles can contribute to the effective and efficient management and planning of supply chain activities.

A DESCRIPTION OF EACH CHAPTER

Anticipation of Demand in Supply Chains

The main objective of studying decentralized supply chains is to demonstrate that a better inter-firm collaboration can lead to a better overall performance of the system. Many researchers studied a phenomenon called Downstream Demand Inference (DDI), which presents an effective demand management strategy to deal with forecast problems. DDI allows the upstream actor to infer the demand received by the downstream one without information sharing. Recent study showed that DDI is possible with Simple Moving Average (SMA) forecast method, and was verified especially for an autoregressive AR(1) demand process. This chapter extend the strategy's results by developing Mean Squared Error and Average Inventory level expressions for causal invertible ARMA(p,q) demand under DDI strategy, No Information Sharing (NIS) and Forecast Information Sharing (FIS) strategies. The authors analyze the sensibility of the performance metrics in respect with Lead-time, SMA and ARMA(p,q) parameters, and compare DDI results with the NIS and FIS strategies' results.

The Distribution and Pickup of Goods: A Literature Review and Survey

The literature of vehicle scheduling problems is rich with different approaches, which try to schedule the distribution of products to a network of clients. In this case, the vehicle routing problem with deliveries and pickups of goods is an extension of vehicle routing problem, in which goods are transported from a depot (or multiple depots) to customers, as well from customers to the depots. There is tremendous work in the literature of this problem. Freight transport management deals with all distribution problems along the supply chain. This paper presents a comprehensive review and survey of this literature. The literature is classified into four fundamental classes according to the way of the customers' visit and methods used for solving then. Then, different variants are generated according to the elements of the proposed framework. During this paper, based on a proposed framework the authors analyze the literature of the vehicle routing problem with deliveries and pickups and as the result the researchers propose a new classification where they gave a short modeling of it.

Hierarchical Planning Models for Public Healthcare Supply Chains

This chapter focuses on the hierarchical planning and execution for supply chain management in public healthcare services. We first introduce tiered organizational and services delivery structure of public healthcare services followed by various supply chain issues that public healthcare services encounters. We then review hierarchical planning and execution discussions for the strategic, tactical and operational decisions in supply chain literature. We continue our discussion with public healthcare services cases on medicine and equipment maintenance supply chains. We compare hierarchical planning execution discussions in supply chain management literature vis-a-vie healthcare services cases. Our main argument is that much can be gained by the public healthcare services by striving for reduced information asymmetry and employing appropriate functional aggregation at various levels of the hierarchically organized public healthcare supply chains.

Impact of Green Supply Chain Management on Competitive Advantage of Business Organizations in Sri Lanka

Organizations adopt many strategies to gain competitive advantage. The main strategy is adapting Green Practices. Cost-benefit and customer value enhancement are another two strategies. Combining both above elements simultaneously organizations can get a superior competitive advantage. There are contradictory findings on cost-benefit element to adapting GSCM and no clear theory how to combine elements affect to gain competitive advantage. The primary objective: to identify the impact on GSCM on competitive advantage on business organizations in Sri Lanka. Sample technique was convenience sampling method. Data collected from 30 organizations practicing green practices in Sri Lanka. The data were analyzed using descriptive analysis, correlation coefficient, and simple regression model. The results show that there is a strong positive relationship between GSCM and competitive advantage and rather than consider about one factor to gain a competitive advantage, it's better to apply both cost-benefit and customer value enhancement simultaneously.

Meta Heuristic Approaches for Supply Chain Management

According to the author, supply Chain Management is essentially a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system wide costs or maximize profits while satisfying service level requirements. To solve complex problems in SCM and to obtain optimization, various meta-heuristics algorithms can be used. This chapter introduces the background of various meta-heuristic algorithms for SCM Next, the author discusses the challenges involved in SCM and the related work based on meta heuristic algorithms. Finally, the author explains the future research directions.

Multi-Objective Decision Analysis in Strategic Supply Chain

This chapter introduces the impact of competitive strategy on strategic supply chain network design decisions. The aim of increasing competitive advantage forces firms to deal with multiple conflicting objectives. Since, supply chains are affiliate networks including multiple parties, accomplishing a solitary objective corresponds to an inadequate effort to maintain the sustainability of supply chain. The overall integrity and sustainability of the supply chain can be provided by satisfying the expectations of each parties. The loyalty in the supply chain is achieved by offering distinguished service among suppliers and customers rather than delivering almost same services. This can only be achieved through network design models by taking into account multiple conflicting objectives. The firm's competitive strategy defines a particular set of objectives to achieve specific goals on these performance attributes. This study examines main problem domains in SC design, strategic performance measures and recent literature on single/multiple objective models.

A Case Study for Supply Chain Management Using System Dynamics

System dynamics is an interdisciplinary problem-solving methodology that utilizes several significant thinking skills such as dynamic thinking and cause-and-effect thinking. System dynamics is a disciplined collaborative approach that could accelerate learning by combining a multifaceted perspective that provides insight into complex and interactive issues. System dynamics is designed to model, analyze and improve socio-economic and administrative systems using a feedback perspective. Dynamic structured administrative problems are modeled by mathematical equations and using computer software. Dynamic constructions of model variables are obtained using computer simulations. In this chapter, a system dynamics model will be developed for supply chain management. The case study will be developed using VENSIM package program.

CONCLUSION

The book is written to cover the interests of a wide variety of audiences ranging from academic researchers, students and practitioners. It features numerous methods and technics for hierarchical planning and information sharing in supply chain management.

This work is an excellent book that pool together the literature related to hierarchical planning, and presents some new methods and algorithms as well. This book is clearly written and makes good use of tables and diagrams to illustrate the hierarchical planning and information sharing in supply chain management.

I recommend this book for a variety of audiences: professors, researchers, students and practitioners who are interested to obtain a good understanding of the current state of hierarchical planning and information sharing in supply chain management and to implement them in the service and goods industries.

Chapter 1
Anticipation of Demand in Supply Chains

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ABSTRACT

The main objective of studying decentralized supply chains is to demonstrate that a better interfirm collaboration can lead to a better overall performance of the system. Many researchers studied a phenomenon called downstream demand inference (DDI), which presents an effective demand management strategy to deal with forecast problems. DDI allows the upstream actor to infer the demand received by the downstream one without information sharing. Recent study showed that DDI is possible with simple moving average (SMA) forecast method and was verified especially for an autoregressive AR(1) demand process. This chapter extends the strategy's results by developing mean squared error and average inventory level expressions for causal invertible ARMA(p,q) demand under DDI strategy, no information sharing (NIS), and forecast information sharing (FIS) strategies. The authors analyze the sensibility of the performance metrics in respect with lead-time, SMA, and ARMA(p,q) parameters, and compare DDI results with the NIS and FIS strategies' results.

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INTRODUCTION

A supply chain consists of two or more agents that integrate with each other to create and deliver value to end customers. A decentralized supply chain is characterized by independent agents with asymmetrical information. In fact, in this form of supply chain, most supply chain agents may not share information due to privacy policies, information quality, or system incompatibilities. Each actor holds his own set of information and tries to maximize his objective (minimizing costs / minimizing stocks) according to the available settings. As a result, agents control their own activities in order to improve their own competitiveness, which leads them to make decisions that maximize their local performance by ignoring other agents or even the end consumer. These decisions are short-sighted because they do not take into account the performance of all partners to satisfy this consumer.

Over the last years, a major movement of business partner's integration to implement advanced and collaborative replenishment processes has appeared. Supply Chain Management (SCM) has emerged in the service and production sectors to identify and take advantage of new improvement sources in business competitiveness. SCM therefore proposes strategies and methods to reduce the costs whose origin is mainly due to poor coordination of operations. The observation of the implementation of the collaboration method is very encouraging. Companies can better satisfy the consumer, by offering more product availability, services with fewer delays, while being more efficient by having less inventory, making better use of resources and achieving a better return on employed capital.

One of the most important data to be shared is consumer's demand. In most industrial sectors, the volatility of final customer demand must be well taken into account by all actors in the supply chain, as demand is the primary driver of the benefits for the entire supply chain. Predicting customer demand can be the key to secure inventory levels and lower inventory costs. Disney and Towill (2002) and Ireland and Crum (2006) reported that inventory levels can be reduced to 50% and inventory costs reduced to 40%, leading to competitive success. In recent years, numerous studies have highlighted the importance of information sharing in the supply chain (Barratt, 2004, Lambert and Cooper, 2000, Lau and Lee, 2000, Trkman et al., 2006).

The question of this chapter is motivated by the work recently published by Ali et al. (2017), who investigated three different strategies for examining the value of information sharing in a two-tier supply chain under the assumption of an $AR(1)$. demand process. The first strategy, called No Information Sharing (NIS), is a decentralized demand management strategy in which demand information is not shared and the upstream actor will simply base its forecast on orders received from the downstream actor. The second strategy, called Forecast Information Sharing (FIS), presents a centralized demand management strategy in which the upstream actor has access to downstream actor demand and bases its forecast on shared information. Between the NIS strategy, which presents sub-optimal solutions and the FIS strategy, which presents optimal solutions, a third approach, called the Inbound Demand Inference (DDI) strategy, makes it possible to improve the performance of the decentralized system in order to obtain quasi-optimal solutions. Instead of sharing demand information, both actors in the supply chain derive the demand and the demand deduced from the customer uses in the forecast. Ali and Boylan (2011) showed that DDI cannot be applied with optimal prediction methods, but only when the downstream actor uses the Simple Moving Average (SMA) forecast method.

The results of Ali et *al*. (2017) were encouraging. First, the FIS strategy is, in most cases, the best management strategy because the actors behave optimally by sharing information and there is no need of inference. Second, the DDI strategy improves on NIS by reducing the Mean Squared Error (MSE) for higher autoregressive parameter values (beyond a certain breakpoint), and reducing inventory costs for higher values of Lead-time and SMA parameter. The improvements in MSE and inventory costs were not been proportional, which confirms the conclusion of Boylan and Syntetos (2006) who mention that precision involvement (inventory costs) is the final measure to be taken, rather than accuracy itself. Information sharing values were evaluated especially when the demand followed an $AR(1)$, $MA(1)$, and $ARMA(1,1)$ processes. In this chapter, the authors extend literature results to situations where demand follows an invertible causal $ARMA(p,q)$. The researchers show through simulation, that DDI always outperforms NIS in terms of Average Inventory level $(\tilde{I}_t)$, and for the most of cases in terms of MSE.

The chapter is organizing as follows. The first section is devoted to the literature review. In second section, the authors derive the MSE and $\tilde{I}_t$ expressions, for an invertible causal $ARMA(p,q)$ demand process, under NIS, DDI and FIS strategies. The authors simulate different $ARMA(p,q)$ processes and generalize MSE and $\tilde{I}_t$ behaviors for variable parameters under the considered strategies in the third section. Finally, in the fourth section, the researchers present the conclusions and implications of the paper, as well as the natural avenues for future research.

BACKGROUND

Information sharing among supply chain links can help achieve important benefits such as increased productivity, improved policy making and integrated services. Various papers (Chen et *al*, 2000; Lee et *al.*, 2000) have shown that sharing demand information reduces the so-called "Bullwhip Effect". The bullwhip effect is essentially the phenomenon of demand variability amplification along a supply chain, from the retailers, distributors, manufacturer, and the manufacturers' suppliers, and so on. Lee et *al*. (2000) characterize this phenomenon as demand distortion, which can create problems for suppliers, such as grossly inaccurate demand forecasts, low capacity utilization, excessive inventory, and poor customer service. Letting the upstream links have access to point-of-sales data, the harmful effect of demand distortion is improving. The most celebrated implementation of demand information sharing is Wal-Mart's Retail Link program, which provides on-line summary of point-of-sales data to suppliers such as Johnson and Johnson, and Lever Brothers (Gill and Abend, 1997). Indeed, demand information sharing between a downstream actor to his formal supplier can be viewed as the cornerstone of initiatives, such as Quick Response (QR) and Efficient Consumer Response (ECR). Often times, information sharing is embedded in programs like Vendor Managed Inventory (VMI) or Continuous Replenishment Programs (CRP). Major successes of such programs have been reported at companies like Campbell Soup (Clark, 1994) and Barilla SpA (Hammond, 1993).

Although it was accepted by academic researchers and industrial decision makers, that information sharing and managerial coordination generally lead to improved supply chain performance (La Londe and Ginter, 2004), the potential weight of improvement and performance allocation through supply chain actors stay fuzzy. Cachon and Fisher (2000) report that information sharing benefits through different researches is varying between 0% and 35% of total costs. The large deviation of reported results appears, in some way, correlated to supply chains sectors, problems statements and models assumptions.

Sahin and Robinson (2005) analyses and identifies whether information sharing or coordination are the source of supply chain improvement, analyses benefits allocation across supply chain actors and study the relationship between environmental factors and cost decline. The authors reported a reduction of 47.58% in cost when adopting a centralized strategy.

Based on a two-level decentralized supply chain, (Yu et *al*., 2001) illustrate the benefits of information sharing. From the comparison of cost savings and inventory reductions, the authors concluded that Pareto improvement is achieved in the respect of the whole supply chain performance, but at the same time, the benefits of the manufacturer are more valuable than the ones of the retailer. Hence, they recommend that partnership initiative must be taken by the manufacturer and give some collaboration incentives such as sharing logistic costs or guarantying supply reliability.

Despite all the potential advantages and benefits procured by information sharing, the lack of availability of information systems is one of the most common barriers to information sharing (Ali et *al*., 2017). SCM World (Courtin, 2013) report that many companies are hampered by the high investment costs and system implementation issues associated with formal information sharing. Negotiation is the common issue to reduce supply chain parties' costs, as monetary losses remain the main reason for investment blockage (Klein et *al*., 2007). Information systems costs are composed of the initial purchase costs and the time-implementation costs (Fawcett et *al*., 2007). Despite developers are constantly trying to find compatibility solutions, companies tend to resist change because of intra-organizational problems. Even when companies succeed in implementing information systems, the problem becomes a lack of trust and a lack of dialogue and sharing (Mendelson, 2000). Indeed, each partner is wary of the possibility of other partners abusing information and reaping all the benefits from information sharing (Lee and Whang, 2000). Hence, trust presents an important factor so that decision makers only share information with their trusted parties.

Besides these information-sharing inhibitors, even when information technology and trust exist between partners, another type of brakes can persist. It is firstly about information precision when decision makers do not trust shared information in terms of quality and estimate that error is relatively high (Forslund and Jonsson, 2007). Information leakage effect can also be a reason to frame information sharing. Managers always fear the fact that the shared information can be obtained or deduced by competitors who will react to the information sharing activity. As example, Ward (wardsauto.com) conducted a survey of 447 car suppliers in which 28% of survey respondents said their intellectual property was revealed by at least one Detroit car manufacturer and 16% said their intellectual property was revealed by car manufacturers (Anand and Goyal, 2009). As result, the reaction of the competitors may change the benefits among the parties involved in information sharing (Li, 2002). Wal-Mart announced that it would no longer share its information with other companies like Inc and AC Nielson as Wal-Mart considers data to be a top priority and fears information leakage (Hays, 2004). Hence, many companies are conducting to control their information flows, which can lead to additional operational costs (Anand and Goyal, 2009).

In the midst of all these discussions, Downstream Demand Inference appear as topical subject in the scientific community. It is referring to a situation where the upstream actor of a supply chain, can infer the demand occurring at the downstream actor, without need of formal information sharing. A stream of papers, such as Raghunathan (2001) and Zhang (2004), demonstrate that received orders contain already demand information. Hence, they show that demand information can be mathematically concluded from the order history of the downstream actor.

Researchers on this stream of papers are based on two assumptions: The first one is the fact that orders received from the retailer already contain the customer's demand information. The second one is that the demand process and its parameters are known throughout all the supply chain. Hence, if this is always true, FIS is invaluable. In the paper of Ali and Boylan (2011), the authors present feasibility principles and show that inferring customer demand in a precise manner by an upstream member is impossible if model's hypotheses are strictly realistic. Thus, they conclude that FIS has value in supply chains. These authors also showed that DDI cannot be applied with optimal forecasting methods but only with Simple Moving Average (SMA) method, which is widely used in the literature. This forecast method is based on the *N* most recent observations and in every future period, the oldest observation is dropped out and exchanged by the last observation. As Ali and Boylan (2011) showed that, if a downstream actor accepts to use SMA method for his forecasts, the upstream actor will be able to infer the actual downstream customer demand, Ali et *al*. (2017) applied DDI on real sales data and discussed the practical implications. The authors showed that DDI outperforms NIS in terms of forecast *MSE* and inventory costs under the assumption of an $AR\left(1\right)$ demand model and for high values of autoregressive coefficient. They also studied the sensibility of DDI with regard to SMA's order N and lead-time L and found that DDI is valuable for high values of N and relatively low values of L. As future works, Ali et *al*. (2017) propose to extend their research for a more generalized $ARMA\left(p,q\right)$ demand model.

Considering more realistic assumptions into demand-models stays one of the most important directions in inventory theory (Graves, 1999). Many researchers have investigated the dependence of the value of sharing information on the time-series structure of the demand process using an Autoregressive Moving Average (ARMA) methodology. It has been argued that demands over consecutive time periods are rarely statistically independent (Kahn, 1987; Graves, 1999; Lee et *al*, 2000). Therefore, it would be appropriate to model the demand (tourism, fuel, food products, machines, etc.) process as auto-correlated time series as they are long lifecycle goods. Based on these recommendations, the authors move on to next section in order to assess DDI performance under a more realistic and generalized $ARMA\left(p,q\right)$ demand model, in comparison with NIS and FIS strategies.

FRAMEWORK MODEL

The authors base the modeling framework on the work of Lee et *al*., (2000) and Ali et *al*. (2017). The researchers consider a simple two-level supply chain formed by a producer and a retailer, and consider the same model's assumptions, except the time-series demand structure. As in above mentioned works, it is assumed that replenishment policy follows a periodic review system, where downstream actors place their orders at upstream actors after examining their respective inventory levels. Indeed, at time period t, demand D_t is realized at the retailer who observes his inventory level and then places and order Y_t before the end of the period. The producer prepared the required quantity order Y_t, and ships it to the retailer, who will receive it at period $t+L+1$. Here, L presents the replenishment time of both production and shipment. On one hand, it's assumed that there is no order cost. On the other hand, unit inventory holding cost and shortage cost are fixed and denoted respectively by h and s. It's also assumed that both producer and retailer adopt Order-Up-To policy which minimizes the total costs over infinite time horizon (Lee et *al*., 2000).

The authors assume that demand arriving at the retailer is an invertible causal $ARMA(p,q)$ process (see properties 1 and 2 stated below). Let D_t be the demand process at the retailer, such as:

$$D_t = c + \sum_{j=1}^{p} \phi_j D_{t-j} + \xi_t + \sum_{j=1}^{q} \theta_j \xi_{t-j} \tag{1}$$

where $c \geq 0$ determines the unconditional mean of the process D_t, $\phi_j \in [-1,1]$ are Autoregressive coefficients $(j = 1,..,p)$, $\theta_j \in [-1,1]$ are Moving Average coefficients $(j = 1,..,q)$ and $\xi_t \to N(0,\sigma_\xi^2)$ are independent and identically distributed $\forall t \in [0,+\infty[$. Please note that for consideration of all $ARMA(p,q)$ models, the authors don't exclude cases where $q = 0$ or $p = 0$. In the case where $q = 0$, the authors consider causal $AR(p)$ demand processes, and in the case where $p = 0$, the authors consider invertible $MA(q)$ demand processes.

In addition, the authors state the following properties of time-series (Shumway and Stoffer, 2011) which will be useful to our theoretical analysis.

Property 1: Causality of an $ARMA(p,q)$ process. An $ARMA(p,q)$ model is causal if and only if $\Phi_p(z) \neq 0$ for $|z| \leq 1$. Equivalently, the process is causal only if $\Phi_p{}'s$ roots lie outside the unit circle.

Property 2: Invertibility of an $ARMA(p,q)$ process. An $ARMA(p,q)$ model is invertible if and only if $\Theta_q(z) \neq 0$ for $|z| \leq 1$. Equivalently, the process is invertible only if $\Theta_q{}'s$ roots lie outside the unit circle.

Property 3: The Ψ weigths for an $ARMA(p,q)$ process. An process is causal if there is a $\Psi(z) = \psi_0 z^0 + \psi_1 z^1 + \psi_2 z^2 + \ldots$ with $\sum_{j=0}^{+\infty} |\psi_j| < +\infty$ and

$$x_t = \Psi(z)\xi_t = \left(\sum_{j=0}^{+\infty} \psi_j z^j\right)\xi_t = \left(\psi_0 z^0 + \psi_1 z^1 + \psi_2 z^2 + \ldots\right)\xi_t = \sum_{j=0}^{+\infty} \psi_j \xi_{t-j} \tag{2}$$

where ψ_j denotes Ψ weigths which can be calculated as follows:

$$\psi_j = \sum_{k=1}^{p} \phi_k \psi_{j-k}, Max(p, q+1) \leq j$$

with initial conditions

$$\psi_j = \theta_j + \sum_{k=1}^{j} \phi_k \psi_{j-k}, 0 < j < Max(p, q+1), \psi_0 = 1.$$

The representation (2) is called the Infinite Moving Average Representation (IMAR) of x_t.

Mean Squared Error Generalization Under $ARMA(p,q)$ Demand Model

At period $(t+1)$, the demand D_{t+1} arriving at the retailer is expressed by (3):

$$D_{t+1} = c + \sum_{j=1}^{p} \phi_j D_{t+1-j} + \xi_{t+1} + \sum_{j=1}^{q} \theta_j \xi_{t+1-j} \tag{3}$$

The authors follow standard time-series methods and we define d_t as the mean-centered demand process as follows:

$$d_t = D_t - \mu_d \tag{4}$$

where

$$\mu_d = \frac{c}{\phi_0 - \sum_{j=1}^{p} \phi_j} = c\left(1 - \sum_{j=1}^{p} \phi_j\right)^{-1}$$

Then, the demand is expressed by (5):

$$D_t = d_t + \mu_d = d_t + c\left(1 - \sum_{j=1}^{p} \phi_j\right)^{-1} \tag{5}$$

Derivation of the Forecast MSE Expression Under the DDI Strategy

Under the DDI strategy, the retailer passes the demand parameters and process to the producer who will infer the demand at the retailer. Under the DDI strategy, the forecast of the demand is based on Simple Moving Average (SMA) method, which can be expressed at period $(t+1)$ by:

$$f_{t+1} = \frac{1}{N}\sum_{k=0}^{N-1} D_{t-k} = \mu_d + \frac{1}{N}\sum_{k=0}^{N-1} d_{t-k} = \mu_d + \frac{d_t + d_{t-1} + d_{t-2} + \ldots + d_{t-N+1}}{N} \tag{6}$$

Then, MSE is expressed over an interval equal to the lead-time L plus one time unit review period:

$$MSE^{DDI} = Var\left[\sum_{i=1}^{L+1}\left(D_{t+i} - f_{t+i}\right)\right] = Var\left[\sum_{i=1}^{L+1} D_{t+i} - \left(L+1\right) f_{t+1}\right]$$

$$\Leftrightarrow MSE^{DDI} = Var\left(\sum_{i=1}^{L+1} D_{t+i}\right) + \left(L+1\right)^2 Var\left(f_{t+1}\right) - 2\left(L+1\right) Cov\left(\sum_{i=1}^{L+1} D_{t+i}, f_{t+1}\right) \quad (7)$$

The authors first calculate the three terms of equation (7). For this purpose, it's necessary to state the Auto-covariance function for an $ARMA\left(p,q\right)$ process. The general homogenous equation for Auto-covariance coefficients of a causal $ARMA\left(p,q\right)$ process (Brockwell and Davis, 1991) can be mathematically written by:

$$\gamma_k = Cov\left(d_{t+k}, d_t\right) = \sum_{j=1}^{p} \phi_j \gamma_{k-j} \; if \; Max\left(p, q+1\right) \le k$$

with initial conditions

$$\gamma_k = \sum_{j=1}^{p} \phi_j \gamma_{k-j} + \sigma_\xi^2 \sum_{j=k}^{q} \theta_j \psi_{j-k} \; if \; 0 \le k < Max\left(p, q+1\right)$$

Stated below, another way to express Auto-covariance function can be more helpful for implementation.

$$\gamma_k = \sigma_\xi^2 \sum_{j=1}^{\infty} \psi_j \psi_{j+|k|}$$

Then, the authors can calculate the first term of equation (7).

$$Var\left(\sum_{i=1}^{L+1} D_{t+i}\right) = \sum_{i=1}^{L+1} Var\left(D_{t+i}\right) + 2\sum_{i=1}^{L} \sum_{j=i+1}^{L+1} Cov\left(D_{t+i}, D_{t+j}\right)$$

$$\Leftrightarrow Var\left(\sum_{i=1}^{L+1} D_{t+i}\right) = \sum_{i=1}^{L+1} Var\left(d_{t+i} + \mu_d\right) + 2\sum_{i=1}^{L} \sum_{j=i+1}^{L+1} Cov\left(d_{t+i} + \mu_d, d_{t+j} + \mu_d\right)$$

$$\Leftrightarrow Var\left(\sum_{i=1}^{L+1} D_{t+i}\right) = \sum_{i=1}^{L+1} Var\left(d_{t+i}\right) + 2\sum_{i=1}^{L}\sum_{j=i+1}^{L+1} Cov\left(d_{t+i}, d_{t+j}\right)$$

$$\Leftrightarrow Var\left(\sum_{i=1}^{L+1} D_{t+i}\right) = \sum_{i=1}^{L+1} \gamma_0 + 2\sum_{i=1}^{L}\sum_{j=i+1}^{L+1} Cov\left(d_{t+i}, d_{t+j}\right)$$

$$\Leftrightarrow Var\left(\sum_{i=1}^{L+1} D_{t+i}\right) = \left(L+1\right)\gamma_0 + 2\sum_{i=1}^{L}\left[Cov\left(d_{t+i}, d_{t+i+1}\right) + \ldots + Cov\left(d_{t+i}, d_{t+L+1}\right)\right]$$

$$\Leftrightarrow Var\left(\sum_{i=1}^{L+1} D_{t+i}\right) = \left(L+1\right)\gamma_0 + 2\begin{bmatrix}\left(Cov\left(d_{t+1}, d_{t+2}\right) + \ldots + Cov\left(d_{t+1}, d_{t+L+1}\right)\right) \\ + \left(Cov\left(d_{t+2}, d_{t+3}\right) + \ldots + Cov\left(d_{t+2}, d_{t+L+1}\right)\right) + \ldots \\ + \left(Cov\left(d_{t+L-1}, d_{t+L}\right) + Cov\left(d_{t+L-1}, d_{t+L+1}\right)\right) + Cov\left(d_{t+L}, d_{t+L+1}\right)\end{bmatrix}$$

$$\Leftrightarrow Var\left(\sum_{i=1}^{L+1} D_{t+i}\right) = \left(L+1\right)\gamma_0 + 2\left[\left(\gamma_1 + \ldots + \gamma_L\right) + \left(\gamma_1 + \ldots + \gamma_{L-1}\right) + \ldots + \left(\gamma_1 + \gamma_2\right) + \gamma_1\right]$$

$$\Leftrightarrow Var\left(\sum_{i=1}^{L+1} D_{t+i}\right) = \left(L+1\right)\gamma_0 + 2\left(\gamma_L + 2\gamma_{L-1} + 3\gamma_{L-2} + \ldots + L\gamma_1\right)$$

Hence

$$Var\left(\sum_{i=1}^{L+1} D_{t+i}\right) = \left(L+1\right)\gamma_0 + 2\sum_{i=1}^{L} i\,\gamma_{L+1-i}$$

Then, the authors calculate the second term of equation (7).

$$Var\left(f_{t+1}\right) = Var\left(\mu_d + \frac{1}{N}\sum_{k=0}^{N-1} d_{t-k}\right) = \frac{1}{N^2} Var\left(\sum_{k=0}^{N-1} d_{t-k}\right)$$

$$\Leftrightarrow Var\left(f_{t+1}\right) = \frac{1}{N^2}\left[\sum_{k=0}^{N-1} Var\left(d_{t-k}\right) + 2\sum_{k=0}^{N-2}\sum_{l=k+1}^{N-1} Cov\left(d_{t-k}, d_{t-l}\right)\right]$$

$$\Leftrightarrow Var\left(f_{t+1}\right)=\frac{1}{N^2}\left[N\gamma_0+2\sum_{k=0}^{N-2}\left(Cov\left(d_{t-k},d_{t-(k+1)}\right)+\ldots+Cov\left(d_{t-k},d_{t-(N-1)}\right)\right)\right]$$

$$\Leftrightarrow Var\left(f_{t+1}\right)=\frac{1}{N^2}\left[N\gamma_0+2\left[\begin{array}{l}\left(Cov\left(d_t,d_{t-1}\right)+\ldots+Cov\left(d_t,d_{t-(N-1)}\right)\right)\\+\left(Cov\left(d_{t-1},d_{t-2}\right)+\ldots+Cov\left(d_{t-1},d_{t-(N-1)}\right)\right)\\+\ldots+Cov\left(d_{t-(N-2)},d_{t-(N-1)}\right)\end{array}\right]\right]$$

$$\Leftrightarrow Var\left(f_{t+1}\right)=\frac{1}{N^2}\left[N\gamma_0+2\left[\left(\gamma_1+\ldots+\gamma_{N-1}\right)+\left(\gamma_1+\ldots+\gamma_{N-2}\right)+\ldots+\left(\gamma_1+\gamma_2\right)+\gamma_1\right]\right]$$

$$\Leftrightarrow Var\left(f_{t+1}\right)=\frac{1}{N^2}\left[N\gamma_0+2\left[\gamma_{N-1}+2\gamma_{N-2}+3\gamma_{N-3}+\ldots+\left(N-1\right)\gamma_1\right]\right]$$

Hence

$$\Leftrightarrow Var\left(f_{t+1}\right)=\frac{1}{N^2}\left[N\gamma_0+2\sum_{j=1}^{N-1}j\gamma_{N-j}\right]$$

$$\Leftrightarrow\left(L+1\right)^2 Var\left(f_{t+1}\right)=\left(L+1\right)^2\left[\frac{\gamma_0}{N}+\frac{2}{N^2}\sum_{j=1}^{N-1}j\gamma_{N-j}\right]$$

And finally, the authors calculate the third term of equation (7).

$$Cov\left(\sum_{i=1}^{L+1}D_{t+i},f_{t+1}\right)=Cov\left(\left(L+1\right)\mu_d+\sum_{i=1}^{L+1}d_{t+i},\mu_d+\frac{1}{N}\sum_{k=0}^{N-1}d_{t-k}\right)$$

$$\Leftrightarrow Cov\left(\sum_{i=1}^{L+1}D_{t+i},f_{t+1}\right)=\frac{1}{N}Cov\left(\sum_{i=1}^{L+1}d_{t+i},\sum_{k=0}^{N-1}d_{t-k}\right)=\frac{1}{N}\sum_{i=1}^{L+1}\sum_{k=0}^{N-1}Cov\left(d_{t+i},d_{t-k}\right)$$

$$\Leftrightarrow Cov\left(\sum_{i=1}^{L+1} D_{t+i}, f_{t+1}\right) = \frac{1}{N}\sum_{i=1}^{L+1}\sum_{k=0}^{N-1} Cov\left(d_{t+i+k}, d_t\right) = \frac{1}{N}\sum_{i=1}^{L+1}\sum_{k=0}^{N-1}\gamma_{i+k}$$

Hence

$$-2\left(L+1\right)Cov\left(\sum_{i=1}^{L+1} D_{t+i}, f_{t+1}\right) = -\frac{2\left(L+1\right)}{N}\sum_{i=1}^{L+1}\sum_{k=0}^{N-1}\gamma_{i+k}$$

So by adding all the obtained three terms, MSE^{DDI} is expressed by (8):

$$MSE^{DDI} = \left(L+1\right)\gamma_0 + 2\sum_{j=1}^{L} j\,\gamma_{L+1-j} + \left(L+1\right)^2\left[\frac{\gamma_0}{N} + \frac{2}{N^2}\sum_{j=1}^{N-1} j\,\gamma_{N-j}\right] - \frac{2\left(L+1\right)}{N}\sum_{j=1}^{L+1}\sum_{k=0}^{N-1}\gamma_{j+k} \quad (8)$$

MSE^{DDI} is a function of lead-time L, SMA forecast's order N and auto-covariance function γ_j at time periods $j = 0,\ldots,L+N$. As γ_j is a decreasing function on j, and by looking at the four components of (8), it becomes clear that the third component overweight the fourth one with respect to N. Indeed, as the third component is inversely proportional to N and N^2, the authors conclude that MSE^{DDI} reduces as the SMA order N increases. In the same way, the third component, which is proportional to L^2. in addition to the first component, overweight the fourth one with respect to lead-time L. Furthermore, by looking at third and fourth component, it's expected that MSE^{DDI} will be more sensitive to N, for higher values of L. Reciprocally, MSE^{DDI} is expected to be less sensitive to L, for higher values of N. Then, the researchers move on to derivate MSE expression under FIS strategy.

Derivation of the Forecast MSE Expression Under the FIS Strategy

Under FIS strategy, the producer receives formal demand information from the retailer and so holds an historical data of demand. The researchers denote by $\tau_t = \left\{d_t, d_{t-1},\ldots,d_{t-T}\right\}$ the set of demand information hold by the producer at period t. Under the FIS strategy and for an $ARMA\left(p,q\right)$ demand process, the IMAR expression of equation (2) and equation (5) are used. The authors first establish the optimal MMSE forecasting method over a duration of $\left(L+1\right)$ which can be expressed as follows:

$$f_{t+L+1} = E\left(\sum_{i=1}^{L+1} D_{t+i} / \tau_t\right) = E\left(\left(L+1\right)\mu_d + \sum_{i=1}^{L+1} d_{t+i} / \tau_t\right)$$

$$\Leftrightarrow f_{t+l+1} = \left(L+1\right)\mu_d + E\left(\sum_{i=1}^{L+1}\sum_{j=0}^{+\infty}\psi_j \xi_{t+i-j} / \tau_t\right)$$

$$\Leftrightarrow f_{t+l+1} = \left(L+1\right)\mu_d + E\left(\sum_{j=0}^{+\infty}\left(\psi_j \xi_{t+1-j} + \ldots + \psi_j \xi_{t+L+1-j}\right) / \tau_t\right)$$

$$\Leftrightarrow f_{t+L+1} = \left(L+1\right)\mu_d + E\left[\begin{bmatrix}\left(\psi_0 \xi_{t+1} + \ldots + \psi_0 \xi_{t+L+1}\right) + \ldots + \left(\psi_L \xi_{t+1-L} + \ldots + \psi_L \xi_{t+1}\right) \\ + \left(\psi_{L+1}\xi_{t-L} + \ldots + \psi_{L+1}\xi_t\right) + \ldots\end{bmatrix} / \tau_t\right]$$

$$\Leftrightarrow f_{t+L+1} = \left(L+1\right)\mu_d + E\left[\begin{bmatrix}\psi_0 \xi_{t+L+1} + \left(\psi_0 + \psi_1\right)\xi_{t+L} + \ldots + \left(\psi_0 + \ldots + \psi_{L-1}\right)\xi_{t+2} \\ + \left(\psi_0 + \ldots + \psi_L\right)\xi_{t+1} + \left(\psi_1 + \ldots + \psi_{L+1}\right)\xi_{t+1-1} \\ + \left(\psi_2 + \ldots + \psi_{L+2}\right)\xi_{t+1-2} + \ldots\end{bmatrix} / \tau_t\right]$$

$$\Leftrightarrow f_{t+L+1} = \left(L+1\right)\mu_d + E\left[\begin{bmatrix}\psi_0 \xi_{t+L+1} + \left(\psi_0 + \psi_1\right)\xi_{t+L} + \ldots + \left(\psi_0 + \ldots + \psi_{L-1}\right)\xi_{t+2} \\ + \left(\psi_0 + \ldots + \psi_L\right)\xi_{t+1} + \left(\psi_1 + \ldots + \psi_{L+1}\right)\xi_t \\ + \left(\psi_2 + \ldots + \psi_{L+2}\right)\xi_{t-1} + \ldots\end{bmatrix} / \tau_t\right]$$

$$\Leftrightarrow f_{t+L+1} = \left(L+1\right)\mu_d + E\left[\begin{bmatrix}\left(\sum_{j=0}^{0}\psi_j\right)\xi_{t+L+1} + \left(\sum_{j=0}^{1}\psi_j\right)\xi_{t+L} + \ldots + \left(\sum_{j=0}^{L-1}\psi_j\right)\xi_{t+2} \\ + \left(\sum_{j=0}^{L}\psi_j\right)\xi_{t+1} + \left(\sum_{j=1}^{L+1}\psi_j\right)\xi_t + \left(\sum_{j=2}^{L+2}\psi_j\right)\xi_{t-1} + \ldots\end{bmatrix} / \tau_t\right]$$

$$\Leftrightarrow f_{t+L+1} = \left(L+1\right)\mu_d + \left(\sum_{j=0}^{0}\psi_j\right)E\left(\xi_{t+L+1} / \tau_t\right) + \left(\sum_{j=0}^{1}\psi_j\right)E\left(\xi_{t+L} / \tau_t\right) + \ldots + \left(\sum_{j=0}^{L-1}\psi_j\right)E\left(\xi_{t+2} / \tau_t\right)$$
$$+ \left(\sum_{j=0}^{L}\psi_j\right)E\left(\xi_{t+1} / \tau_t\right) + \left(\sum_{j=1}^{L+1}\psi_j\right)E\left(\xi_t / \tau_t\right) + \left(\sum_{j=2}^{L+2}\psi_j\right)E\left(\xi_{t-1} / \tau_t\right) + \ldots$$

As the producer holds historical demand information until date $\left(t-T\right)$, $\xi_{t-j}, \forall j \in \left[T, +\infty\right[$ are not calculable and then the producer obtains an estimator of f_{t+L+1}. As $\xi_t, \xi_{t-1}, \ldots, \xi_{t-T}$ are supposed known for the producer at period t, $E\left(\xi_{t-j} / \tau_t\right) = \xi_{t-j} \ \ \forall j \in \left[0, T\right]$. Consequently,

$$f_{t+l+1} \approx \left(L+1\right)\mu_d + \left(\sum_{j=1}^{L+1}\psi_j\right)\xi_t + \left(\sum_{j=2}^{L+2}\psi_j\right)\xi_{t-1} + \ldots + \left(\sum_{j=T+1}^{L+T+1}\psi_j\right)\xi_{t-T}$$

$$\Leftrightarrow f_{t+L+1} = \left(L+1\right)\mu_d + \sum_{i=0}^{T}\left(\sum_{j=1+i}^{L+1+i}\psi_j\right)\xi_{t-i}$$

And finally,

$$f_{t+L+1} \approx c\left(L+1\right)\left(1-\sum_{j=1}^{p}\phi_j\right)^{-1} + \sum_{i=0}^{T}\left(\sum_{j=1+i}^{L+1+i}\psi_j\right)\xi_{t-i} \tag{9}$$

Then, the authors establish the MSE expression over $\left(L+1\right)$ period under the FIS strategy.

$$MSE^{FIS} = Var\left(\sum_{i=1}^{L+1}D_{t+i} / \tau_t\right) = Var\left(\left(L+1\right)\mu_d + \sum_{i=1}^{L+1}d_{t+i} / \tau_t\right)$$

$$\Leftrightarrow MSE^{FIS} = Var\left(\sum_{i=1}^{L+1}\sum_{j=0}^{+\infty}\psi_j\xi_{t+i-j} / \tau_t\right)$$

$$\Leftrightarrow MSE^{FIS} = Var\left(\sum_{j=0}^{+\infty}\left(\psi_j\xi_{t+1-j} + \ldots + \psi_j\xi_{t+L+1-j}\right) / \tau_t\right)$$

$$\Leftrightarrow MSE^{FIS} = Var\left[\left[\begin{array}{l}\left(\psi_0\xi_{t+1} + \ldots + \psi_0\xi_{t+L+1}\right) + \ldots + \left(\psi_L\xi_{t+1-L} + \ldots + \psi_L\xi_{t+1}\right) \\ + \left(\psi_{L+1}\xi_{t-L} + \ldots + \psi_{L+1}\xi_t\right) + \ldots\end{array}\right] / \tau_t\right]$$

$$\Leftrightarrow MSE^{FIS} = Var\left[\left[\begin{array}{l}\psi_0\xi_{t+L+1} + \left(\psi_0 + \psi_1\right)\xi_{t+L} + \ldots + \left(\psi_0 + \ldots + \psi_{L-1}\right)\xi_{t+2} \\ +\left(\psi_0 + \ldots + \psi_L\right)\xi_{t+1} + \left(\psi_1 + \ldots + \psi_{L+1}\right)\xi_{t+1-1} \\ +\left(\psi_2 + \ldots + \psi_{L+2}\right)\xi_{t+1-2} + \ldots\end{array}\right] / \tau_t\right]$$

$$\Leftrightarrow MSE^{FIS} = Var\left[\left[\begin{array}{l}\psi_0\xi_{t+L+1} + \left(\psi_0 + \psi_1\right)\xi_{t+L} + \ldots + \left(\psi_0 + \ldots + \psi_{L-1}\right)\xi_{t+2} \\ +\left(\psi_0 + \ldots + \psi_L\right)\xi_{t+1} + \left(\psi_1 + \ldots + \psi_{L+1}\right)\xi_t \\ +\left(\psi_2 + \ldots + \psi_{L+2}\right)\xi_{t-1} + \ldots\end{array}\right] / \tau_t\right]$$

$$\Leftrightarrow MSE^{FIS} = Var\left[\left[\begin{array}{l}\left(\sum_{j=0}^{0}\psi_j\right)\xi_{t+L+1} + \left(\sum_{j=0}^{1}\psi_j\right)\xi_{t+L} + \ldots + \left(\sum_{j=0}^{L-1}\psi_j\right)\xi_{t+2} \\ +\left(\sum_{j=0}^{L}\psi_j\right)\xi_{t+1} + \left(\sum_{j=1}^{L+1}\psi_j\right)\xi_t + \left(\sum_{j=2}^{L+2}\psi_j\right)\xi_{t-1} + \ldots\end{array}\right] / \tau_t\right]$$

As noted above that under this strategy, the producer holds historical information until period $\left(t-T\right)$, and assuming the independency of demand error terms, it implies that:

$$\begin{aligned}MSE^{FIS} &= \left(\sum_{j=0}^{0}\psi_j\right)^2 Var\left(\xi_{t+L+1} / \tau_t\right) + \left(\sum_{j=0}^{1}\psi_j\right)^2 Var\left(\xi_{t+L} / \tau_t\right) + \ldots \\ &+ \left(\sum_{j=0}^{L-1}\psi_j\right)^2 Var\left(\xi_{t+2} / \tau_t\right) + \left(\sum_{j=0}^{L}\psi_j\right)^2 Var\left(\xi_{t+1} / \tau_t\right) + \left(\sum_{j=1}^{L+1}\psi_j\right)^2 Var\left(\xi_t / \tau_t\right) \\ &+ \left(\sum_{j=2}^{L+2}\psi_j\right)^2 Var\left(\xi_{t-1} / \tau_t\right) + \ldots + \left(\sum_{j=T+1}^{L+T+1}\psi_j\right)^2 Var\left(\xi_{t-T} / \tau_t\right)\end{aligned}$$

and

$$Var\left(\xi_{t-j} / \tau_t\right) = 0 \;\; \forall j \in \left[0, +\infty\right[$$

Consequently,

$$\Leftrightarrow MSE^{FIS} = \sigma_{\xi}^{2}\left[\left(\sum_{j=0}^{0}\psi_{j}\right)^{2} + \left(\sum_{j=0}^{1}\psi_{j}\right)^{2} + \ldots + \left(\sum_{j=0}^{L-1}\psi_{j}\right)^{2} + \left(\sum_{j=0}^{L}\psi_{j}\right)^{2}\right]$$

And finally, MSE^{FIS} is expressed by (10):

$$MSE^{FIS} = \sigma_{\xi}^{2}\left[\sum_{i=0}^{L}\left(\sum_{j=0}^{i}\psi_{j}\right)^{2}\right] \tag{10}$$

MSE^{FIS} is a function of lead time L. IMAR coefficients ψ_j. $j = 0, \ldots, L$ and is a linear function on σ_{ξ}^{2}. The authors so expect that MSE^{FIS} improves as L increases, especially in a logarithmic manner when they know that ψ is a decreasing function. This finding will be confirmed in section 4. The authors move on to derivate the MSE expression under NIS strategy.

Derivation of the Forecast MSE Expression Under the NIS Strategy

As the demand process at the retailer follows an $ARMA(p,q)$ process, the authors must first know what is the structure of orders quantity process arriving at the producer. Zhang (2004) showed that for an invertible causal $ARMA(p,q)$ demand process at the retailer, the orders at the producer will keep the same autoregressive structure and the moving average structure is a function of autoregressive and IMAR coefficients. The researchers state the ARMA-in-ARMA-out (AIAO) property as it was in the paper of Zhang (2004).

Property 4: AIAO Property.

Let $\beta = \sum_{j=0}^{l}\psi_j$ and $\delta_k = \begin{cases} -\dfrac{\psi_{L+1}}{\beta}, & if\ k = 1 \\ \dfrac{\sum_{j=1}^{k-1}\phi_j\psi_{L+k-j} - \psi_{L+k}}{\beta}, & if\ 1 < k \le p \end{cases}$

The order quantity Y_t follows an $ARMA(p,m)$ process with $m = Max(p, q-L)$ such as:

$$Y_t = c + \sum_{j=1}^{p} \phi_j Y_{t-j} + \tilde{\xi}_t + \sum_{j=1}^{m} \tilde{\theta}_j \tilde{\xi}_{t-j} \tag{11}$$

where $\tilde{\xi}_t = \beta \xi_t$ and the Moving Average coefficients $\tilde{\theta}_k$ are determined from:

Case 1: $m = p$ when $p > q - L$

$$\tilde{\theta}_k = \phi_k + \delta_k$$

Case 2: $m = q - L$ when $p \le q - L$

$$\tilde{\theta}_k = \begin{cases} \phi_k + \delta_k, & \text{if } k \le p \\ \dfrac{\theta_{L+k}}{\beta}, & \text{if } p < k \le q - L \end{cases}$$

The authors define y_t the mean-centered orders quantity at the producer such as:

$$y_t = Y_t - \mu_y = Y_t - \frac{c}{1 - \sum_{j=1}^{p} \phi_j}$$

$$\Leftrightarrow Y_t = y_t + \mu_y = y_t + \frac{c}{1 - \sum_{j=1}^{p} \phi_j} \tag{12}$$

Under the NIS strategy, the producer has no access to demand information at the retailer and thus bases its forecasting only on historical orders quantity. The authors denote by $\rho_t = \left\{ Y_t, Y_{t-1}, \ldots, Y_{t-T} \right\}$ the set of orders quantity information hold by the producer at period t. Using the AIAO property, the authors can see that the causality criteria is hold over the supply chain links thanks to the identical autoregressive structure. It means that, if the demand process at the retailer is causal, then the orders quantity process is also causal.

Hence, the authors can state that the mean-centered orders quantity process has also an IMAR representation with different parameters. Under the NIS strategy and for an $ARMA(p,q)$ demand process, the authors utilize equations (2) and (12) and determine the optimal MMSE forecasting method over a duration $\left(L+1\right)$ which can be expressed as follows:

$$\tilde{f}_{t+L+1} = E\left(\sum_{i=1}^{L+1} Y_{t+i} / \rho_t\right) = E\left(\left(L+1\right)\mu_y + \sum_{i=1}^{L+1} y_{t+i} / \rho_t\right)$$

$$\Leftrightarrow \tilde{f}_{t+L+1} = \left(L+1\right)\mu_y + E\left(\sum_{i=1}^{L+1}\sum_{j=0}^{+\infty}\tilde{\psi}_j\tilde{\xi}_{t+i-j} / \rho_t\right)$$

$$\Leftrightarrow \tilde{f}_{t+L+1} = \left(L+1\right)\mu_y + E\left(\sum_{j=0}^{+\infty}\left(\tilde{\psi}_j\tilde{\xi}_{t+1-j} + \ldots + \tilde{\psi}_j\tilde{\xi}_{t+L+1-j}\right) / \rho_t\right)$$

$$\Leftrightarrow \tilde{f}_{t+L+1} = \left(L+1\right)\mu_y + E\left[\begin{bmatrix}\left(\tilde{\psi}_0\tilde{\xi}_{t+1} + \ldots + \tilde{\psi}_0\tilde{\xi}_{t+L+1}\right) + \ldots + \left(\tilde{\psi}_L\tilde{\xi}_{t+1-L} + \ldots + \tilde{\psi}_L\tilde{\xi}_{t+1}\right) \\ + \left(\tilde{\psi}_{L+1}\tilde{\xi}_{t-L} + \ldots + \tilde{\psi}_{L+1}\tilde{\xi}_t\right) + \ldots\end{bmatrix} / \rho_t\right]$$

$$\Leftrightarrow \tilde{f}_{t+L+1} = \left(L+1\right)\mu_y + E\left[\begin{bmatrix}\tilde{\psi}_0\xi_{t+L+1} + \left(\tilde{\psi}_0 + \tilde{\psi}_1\right)\tilde{\xi}_{t+L} + \ldots + \left(\tilde{\psi}_0 + \ldots + \tilde{\psi}_{L-1}\right)\tilde{\xi}_{t+2} \\ + \left(\tilde{\psi}_0 + \ldots + \tilde{\psi}_L\right)\tilde{\xi}_{t+1} + \left(\tilde{\psi}_1 + \ldots + \tilde{\psi}_{L+1}\right)\tilde{\xi}_{t+1-1} \\ + \left(\tilde{\psi}_2 + \ldots + \tilde{\psi}_{L+2}\right)\tilde{\xi}_{t+1-2} + \ldots\end{bmatrix} / \rho_t\right]$$

$$\Leftrightarrow \tilde{f}_{t+L+1} = \left(L+1\right)\mu_y + E\left[\begin{bmatrix}\tilde{\psi}_0\xi_{t+L+1} + \left(\tilde{\psi}_0 + \tilde{\psi}_1\right)\tilde{\xi}_{t+L} + \ldots + \left(\tilde{\psi}_0 + \ldots + \tilde{\psi}_{L-1}\right)\tilde{\xi}_{t+2} \\ + \left(\tilde{\psi}_0 + \ldots + \tilde{\psi}_L\right)\tilde{\xi}_{t+1} + \left(\tilde{\psi}_1 + \ldots + \tilde{\psi}_{L+1}\right)\tilde{\xi}_t \\ + \left(\tilde{\psi}_2 + \ldots + \tilde{\psi}_{L+2}\right)\tilde{\xi}_{t-1} + \ldots\end{bmatrix} / \rho_t\right]$$

$$\Leftrightarrow \tilde{f}_{t+L+1} = \left(L+1\right)\mu_y + E\left[\begin{bmatrix}\left(\sum_{j=0}^{0}\tilde{\psi}_j\right)\tilde{\xi}_{t+L+1} + \left(\sum_{j=0}^{1}\tilde{\psi}_j\right)\tilde{\xi}_{t+L} + \ldots + \left(\sum_{j=0}^{L-1}\tilde{\psi}_j\right)\tilde{\xi}_{t+2} \\ + \left(\sum_{j=0}^{L}\tilde{\psi}_j\right)\tilde{\xi}_{t+1} + \left(\sum_{j=1}^{L+1}\tilde{\psi}_j\right)\tilde{\xi}_t + \left(\sum_{j=2}^{L+2}\tilde{\psi}_j\right)\tilde{\xi}_{t-1} + \ldots\end{bmatrix} / \rho_t\right]$$

$$\Leftrightarrow \tilde{f}_{t+L+1} = \left(L+1\right)\mu_y + \left(\sum_{j=0}^{0}\tilde{\psi}_j\right)E\left(\tilde{\xi}_{t+L+1} / \rho_t\right) + \left(\sum_{j=0}^{1}\psi_j\right)E\left(\tilde{\xi}_{t+L} / \rho_t\right) + \ldots + \left(\sum_{j=0}^{L-1}\tilde{\psi}_j\right)E\left(\tilde{\xi}_{t+2} / \rho_t\right)$$
$$+\left(\sum_{j=0}^{L}\tilde{\psi}_j\right)E\left(\tilde{\xi}_{t+1} / \rho_t\right) + \left(\sum_{j=1}^{L+1}\tilde{\psi}_j\right)E\left(\tilde{\xi}_t / \rho_t\right) + \left(\sum_{j=2}^{L+2}\tilde{\psi}_j\right)E\left(\tilde{\xi}_{t-1} / \rho_t\right) + \ldots$$

As done for FIS strategy, the same line of reasoning applies. The producer here holds only historical orders quantity from period $\left(t-T\right)$ which implies that the producer obtain an estimator of $\tilde{f}_{t+L+1}$.

As $\tilde{\xi}_t, \tilde{\xi}_{t-1}, \ldots, \tilde{\xi}_{t-T}$ are supposed known for the producer at period t,

$$E\left(\tilde{\xi}_{t-j} / \rho_t\right) = \tilde{\xi}_{t-j} \quad \forall j \in \left[0, T\right]$$

and

$$E\left(\tilde{\xi}_{t+j} / \rho_t\right) = E\left(\tilde{\xi}_{t+j}\right) = \beta E\left(\xi_{t+j}\right) = 0 \, \forall j \in \left[0, +\infty\right[.$$

Consequently,

$$\tilde{f}_{t+L+1} \approx \left(L+1\right)\mu_y + \left(\sum_{j=1}^{L+1}\tilde{\psi}_j\right)\tilde{\xi}_t + \left(\sum_{j=2}^{L+2}\tilde{\psi}_j\right)\tilde{\xi}_{t-1} + \ldots + \left(\sum_{j=T+1}^{L+T+1}\tilde{\psi}_j\right)\tilde{\xi}_{t-T}$$

And finally,

$$\tilde{f}_{t+L+1} \approx c\left(L+1\right)\left(1 - \sum_{j=1}^{p}\phi_j\right)^{-1} + \sum_{i=0}^{T}\left(\sum_{j=1+i}^{L+1+i}\tilde{\psi}_j\right)\tilde{\xi}_{t-i} \qquad (13)$$

The authors move on to develop the MSE over a duration of $\left(L+1\right)$ under the NIS strategy.

$$MSE^{NIS} = Var\left(\sum_{i=1}^{L+1} Y_{t+i} / \rho_t\right) = Var\left(\left(L+1\right)\mu_y + \sum_{i=1}^{L+1} y_{t+i} / \rho_t\right)$$

$$\Leftrightarrow MSE_{NIS} = Var\left(\sum_{i=1}^{L+1}\sum_{j=0}^{+\infty}\tilde{\psi}_j\tilde{\xi}_{t+i-j} / \rho_t\right)$$

$$\Leftrightarrow MSE^{NIS} = Var\left(\sum_{j=0}^{+\infty}\left(\tilde{\psi}_j\tilde{\xi}_{t+1-j} + \ldots + \tilde{\psi}_j\tilde{\xi}_{t+L+1-j}\right) / \rho_t\right)$$

$$\Leftrightarrow MSE^{NIS} = Var\left[\begin{bmatrix}\left(\tilde{\psi}_0\tilde{\xi}_{t+1} + \ldots + \tilde{\psi}_0\tilde{\xi}_{t+L+1}\right) + \ldots + \left(\tilde{\psi}_L\tilde{\xi}_{t+1-L} + \ldots + \tilde{\psi}_L\tilde{\xi}_{t+1}\right) \\ + \left(\tilde{\psi}_{L+1}\tilde{\xi}_{t-L} + \ldots + \tilde{\psi}_{L+1}\tilde{\xi}_t\right) + \ldots\end{bmatrix} / \rho_t\right]$$

$$\Leftrightarrow MSE^{NIS} = Var\left[\begin{bmatrix}\tilde{\psi}_0\xi_{t+L+1} + \left(\tilde{\psi}_0 + \tilde{\psi}_1\right)\tilde{\xi}_{t+L} + \ldots + \left(\tilde{\psi}_0 + \ldots + \tilde{\psi}_{L-1}\right)\tilde{\xi}_{t+2} \\ + \left(\tilde{\psi}_0 + \ldots + \tilde{\psi}_L\right)\tilde{\xi}_{t+1} + \left(\tilde{\psi}_1 + \ldots + \tilde{\psi}_{L+1}\right)\tilde{\xi}_{t+1-1} \\ + \left(\tilde{\psi}_2 + \ldots + \tilde{\psi}_{l+2}\right)\tilde{\xi}_{t+1-2} + \ldots\end{bmatrix} / \rho_t\right]$$

$$\Leftrightarrow MSE^{NIS} = Var\left[\begin{bmatrix}\tilde{\psi}_0\xi_{t+L+1} + \left(\tilde{\psi}_0 + \tilde{\psi}_1\right)\tilde{\xi}_{t+L} + \ldots + \left(\tilde{\psi}_0 + \ldots + \tilde{\psi}_{L-1}\right)\tilde{\xi}_{t+2} \\ + \left(\tilde{\psi}_0 + \ldots + \tilde{\psi}_L\right)\tilde{\xi}_{t+1} + \left(\tilde{\psi}_1 + \ldots + \tilde{\psi}_{L+1}\right)\tilde{\xi}_t \\ + \left(\tilde{\psi}_2 + \ldots + \tilde{\psi}_{L+2}\right)\tilde{\xi}_{t-1} + \ldots\end{bmatrix} / \rho_t\right]$$

$$\Leftrightarrow MSE^{NIS} = Var\left[\begin{bmatrix}\left(\sum_{j=0}^{0}\tilde{\psi}_j\right)\tilde{\xi}_{t+L+1} + \left(\sum_{j=0}^{1}\tilde{\psi}_j\right)\tilde{\xi}_{t+L} + \ldots + \left(\sum_{j=0}^{L-1}\tilde{\psi}_j\right)\tilde{\xi}_{t+2} \\ + \left(\sum_{j=0}^{L}\tilde{\psi}_j\right)\tilde{\xi}_{t+1} + \left(\sum_{j=1}^{L+1}\tilde{\psi}_j\right)\tilde{\xi}_t + \left(\sum_{j=2}^{L+2}\tilde{\psi}_j\right)\tilde{\xi}_{t-1} + \ldots\end{bmatrix} / \rho_t\right]$$

As the error terms of orders quantity are supposed independent, i.e. $\tilde{\xi}_t \perp \tilde{\xi}_{t'}\ \forall t \neq t'$, and on the other hand, as the producer holds information of $\tilde{\xi}_t, \tilde{\xi}_t, \ldots, \tilde{\xi}_{t-T}$ at period t which implies that $Var\left(\tilde{\xi}_{t-j} / \rho_t\right) = 0\ \forall j \in \left[0, T\right]$, it results that:

$$\Leftrightarrow MSE^{NIS} = \sigma_{\tilde{\xi}}^2 \left[\left(\sum_{j=0}^{0} \tilde{\psi}_j \right)^2 + \left(\sum_{j=0}^{1} \tilde{\psi}_j \right)^2 + \ldots + \left(\sum_{j=0}^{L-1} \tilde{\psi}_j \right)^2 + \left(\sum_{j=0}^{L} \tilde{\psi}_j \right)^2 \right]$$

And finally, MSE^{NIS} is expressed by (14):

$$MSE^{NIS} = \sigma_{\tilde{\xi}}^2 \left[\sum_{i=0}^{L} \left(\sum_{j=0}^{i} \tilde{\psi}_j \right)^2 \right] = \beta^2 \sigma_{\xi}^2 \left[\sum_{i=0}^{L} \left(\sum_{j=0}^{i} \tilde{\psi}_j \right)^2 \right] \tag{14}$$

MSE^{NIS} is a function of lead time L, IMAR coefficients $\tilde{\psi}_j$, $j = 0, \ldots, L$ and is a linear function on $\sigma_{\tilde{\xi}}^2$. The authors make the same reasoning as MSE^{FIS} and expect that MSE^{NIS} improves as L increases, especially in a logarithmic manner knowing that $\tilde{\psi}$ is a decreasing function. This finding will also be confirmed in section 4. The authors move on to derive the Average Inventory levels $\tilde{I}_t$ for an $ARMA(p,q)$ demand model.

Average Inventory Level Generalization Under $ARMA(p,q)$ Demand Model

In this section, The authors establish Average Inventory levels $\tilde{I}_t$ expressions associated with DDI, FIS and NIS strategies. The average inventory level under Order-Up-To policy is given by (15) (see Ali et *al*., 2012):

$$\tilde{I}_t = T_t - E\left(\sum_{i=1}^{L+1} Y_{t+i} \right) + \frac{E(Y_t)}{2} \tag{15}$$

where T_t is the producer optimal Order-Up-To inventory level. In this case, T_t is given by (16) (see Lee et *al*., 2000):

$$T_t = M_t + K\sigma_{\tilde{\xi}}\sqrt{V} \tag{16}$$

And M_t and V are respectively, the conditional expectation and conditional variance of the total demand over the lead time, and $K = F_{N(0,1)}^{-1}\left(\frac{s}{s+h}\right)$ for the standard normal distribution $F_{N(0,1)}$. The equation (15) allows to write:

$$\tilde{I}_t^{DDI} = T_t^{DDI} - E\left(\sum_{i=1}^{L+1} Y_{t+i}\right) + \frac{E\left(Y_t\right)}{2} \tag{15a}$$

$$\tilde{I}_t^{FIS} = T_t^{FIS} - E\left(\sum_{i=1}^{L+1} Y_{t+i}\right) + \frac{E\left(Y_t\right)}{2} \tag{15b}$$

$$\tilde{I}_t^{NIS} = T_t^{NIS} - E\left(\sum_{i=1}^{L+1} Y_{t+i}\right) + \frac{E\left(Y_t\right)}{2} \tag{15c}$$

First, the authors express the terms in common, $E\left(Y_t\right)$ and $E\left(\sum_{i=1}^{L+1} Y_{t+i}\right)$. On one hand:

$$E\left(Y_t\right) = \mu_y = \frac{c}{\phi_0 - \sum_{j=1}^{p} \phi_j} = c\left(1 - \sum_{j=1}^{p} \phi_j\right)^{-1}$$

And on the other hand:

$$E\left(\sum_{i=1}^{L+1} Y_{t+i}\right) = \left(L+1\right)\mu_y + E\left(\sum_{i=1}^{L+1} y_{t+i}\right)$$

$$\Leftrightarrow E\left(\sum_{i=1}^{L+1} Y_{t+i}\right) = \left(L+1\right)\mu_y + E\left(\sum_{i=1}^{L+1}\sum_{j=0}^{+\infty} \tilde{\psi}_j \tilde{\xi}_{t+i-j}\right) = \left(L+1\right)\mu_y$$

$$\Leftrightarrow E\left(\sum_{i=1}^{L+1} Y_{t+i}\right) = c\left(L+1\right)\left(1-\sum_{j=1}^{p}\phi_j\right)^{-1}$$

The authors note here that expected orders at time period t and expected orders over time period equal to lead time plus one time period, are stationary over time and simply functions of constant c, lead time L and autoregressive coefficients $\phi_j, j=0,\ldots,p$. Hence, the authors move on to develop the Average Inventory level $\tilde{I}_t$ under the three different strategies.

Derivation of the Average Inventory Level Under DDI Strategy

Under DDI strategy, the producer optimal Order-Up-To inventory level T_t^{DDI} .is expressed by (16a).

$$T_t^{DDI} = M_t^{DDI} + K\sigma_{\tilde{\xi}}\sqrt{V^{DDI}} \tag{16a}$$

where

$$M_t^{DDI} = E\left(\sum_{i=1}^{L+1} f_{t+i}\right) = E\left[\left(L+1\right)f_{t+1}\right]$$

$$\Leftrightarrow M_t^{DDI} = E\left(\left(L+1\right)\left(\mu_d + \frac{1}{N}\sum_{k=0}^{N-1} d_{t-k}\right)\right)$$

$$\Leftrightarrow M_t^{DDI} = \left(L+1\right)\mu_d + \frac{1}{N}E\left(\sum_{k=0}^{N-1} d_{t-k}\right)$$

$$\Leftrightarrow M_t^{DDI} = \left(L+1\right)\mu_d$$

$$M_t^{DDI} = c\left(L+1\right)\left(1-\sum_{j=1}^{p}\phi_j\right)^{-1}$$

and

$V^{DDI} = MSE^{DDI}$

So, by substituting M_t^{DDI} and V^{DDI} expressions in (16a) and then by substituting (16a) expression in (15a), finally $\tilde{I}_t^{DDI}$ is expressed by (17a).

$$\tilde{I}_t^{DDI} = \frac{c}{2\left(1-\sum_{j=1}^{p}\phi_j\right)} + K\sigma_{\tilde{\xi}}\left[\begin{array}{l}\left(L+1\right)\gamma_0 + 2\sum_{i=1}^{L} i\gamma_{L+1-j} \\ +\left(L+1\right)^2\left(\frac{\gamma_0}{N} + \frac{2}{N^2}\sum_{j=1}^{N-1} j\gamma_{N-j}\right) \\ -\frac{2\left(L+1\right)}{N}\sum_{i=1}^{L+1}\sum_{k=0}^{N-1}\gamma_{i+k}\end{array}\right]^{\frac{1}{2}} \tag{17a}$$

$\tilde{I}_t^{DDI}$ in (17a) is a function of constants c and K, autoregressive coefficients ϕ_j, standard error of Orders process $\sigma_{\tilde{\xi}}$, lead-time L, SMA forecast's order N and auto-covariance function γ_j at time periods $j = 0,\ldots,L+N$. As the component in brackets in (20) is the MSE^{DDI}, the authors expect that $\tilde{I}_t^{DDI}$ behave approximatively in the same way as MSE^{DDI}. It implies that $\tilde{I}_t^{DDI}$ reduces as the SMA order N increases and improves when the lead time L increases. The same sensitivity analysis as the one done for MSE^{DDI}, is expected. The authors move on to develop the approximate expressions for the producer's average inventory, under FIS strategy.

Derivation of the Average Inventory Level Under FIS Strategy

Under FIS strategy, the producer optimal Order-Up-To inventory level T_t^{FIS} is expressed by (16b).

$$T_t^{FIS} = M_t^{FIS} + K\sigma_{\tilde{\xi}}\sqrt{V^{FIS}} \tag{16b}$$

where

$$M_t^{FIS} = E\left(\sum_{i=1}^{L+1} D_{t+i} / \tau_t\right) \approx c\left(L+1\right)\left(1-\sum_{j=1}^{p}\phi_j\right)^{-1} + \sum_{i=0}^{T}\left(\sum_{j=1+i}^{L+1+i}\psi_j\right)\xi_{t-i}$$

and

$V^{FIS} = MSE^{FIS}$

So, by substituting M_t^{FIS} and V^{FIS} expressions in (16b) and then by substituting (16b) expression in (15b), finally $\tilde{I}_t^{FIS}$ is expressed by (17b).

$$\tilde{I}_t^{FIS} = \frac{c}{2\left(1-\sum_{j=1}^{p}\phi_j\right)} + \sum_{i=0}^{T}\left(\sum_{j=1+i}^{L+1+i}\psi_j\right)\xi_{t-i} + K\sigma_{\tilde{\xi}}\sigma_{\xi}\left[\sum_{i=0}^{L}\left(\sum_{j=0}^{i}\psi_j\right)^2\right]^{\frac{1}{2}} \qquad (17b)$$

$\tilde{I}_t^{FIS}$ in (17b) is a function of constants c and K, autoregressive coefficients ϕ_j, IMAR coefficients ψ_j, $j = 0,\ldots,T+L+1$, standard error of orders process $\sigma_{\tilde{\xi}}$, standard error of demand process σ_{ξ}, lead-time L, and error terms at time periods $j = t,\ldots,t-T$. It's clear that $\tilde{I}_t^{FIS}$ improve when lead time L increase. The authors expect that $\tilde{I}_t^{FIS}$ would also improve when autoregressive order p increase and especially when $\sum_{j=1}^{p}\phi_j$ approach 1. The authors move on to develop the approximate expressions for the producer's average inventory, under NIS strategy.

Derivation of the Average Inventory Level Under NIS Strategy

Under NIS strategy, the producer optimal Order-Up-To inventory level T_t^{NIS} is expressed by (16c).

$$T_t^{NIS} = M_t^{NIS} + K\sigma_{\tilde{\xi}}\sqrt{V^{NIS}} \qquad (16c)$$

where

$$M_t^{NIS} = E\left(\sum_{i=1}^{L+1}Y_{t+i} / \rho_t\right) \approx c\left(L+1\right)\left(1-\sum_{j=1}^{p}\phi_j\right)^{-1} + \sum_{i=0}^{T}\left(\sum_{j=1+i}^{L+1+i}\tilde{\psi}_j\right)\tilde{\xi}_{t-i}$$

and

$$V^{NIS} = MSE^{NIS}$$

So, by substituting M_t^{NIS} and V^{NIS} expressions in (16c) and then by substituting (16c) expression in (15c), finally $\tilde{I}_t^{NIS}$ is expressed by (17c).

$$\tilde{I}_t^{NIS} = \frac{c}{2\left(1 - \sum_{j=1}^{p} \phi_j\right)} + \sum_{i=0}^{T} \left(\sum_{j=1+i}^{L+1+i} \tilde{\psi}_j \right) \tilde{\xi}_{t-i} + K\sigma_{\tilde{\xi}}^2 \left(\left[\sum_{i=0}^{L} \left(\sum_{j=0}^{i} \tilde{\psi}_j \right)^2 \right] \right)^{\frac{1}{2}} \quad (17c)$$

$\tilde{I}_t^{NIS}$ in (17c) is a function of constants c and K, autoregressive coefficients ϕ_j, IMAR coefficients $\tilde{\psi}_j$, $j = 0,\ldots,T + L + 1$, standard error of orders process $\sigma_{\tilde{\xi}}$, lead-time L, and error terms at time periods $j = t,\ldots,t - T$. It's clear that $\tilde{I}_t^{NIS}$ improve when lead time L increase. The authors expect that $\tilde{I}_t^{FIS}$ would also improve when autoregressive order p increase and especially when $\sum_{j=1}^{p} \phi_j$ approach 1. Before moving on to section 4, the authors precise that the expected findings in this section will be confirmed by simulation. Thus, the researchers continue in section 4, with simulation and empirical analysis in order to generalize conclusions and managerial implications under a general $ARMA(p,q)$ demand model.

SIMULATION AND EMPIRICAL ANALYSIS

The authors develop simulation of different $ARMA(p,q)$ demand and orders processes and generate the performance metrics values and figures under Matlab 2013b software on windows system. In this section, the authors study DDI strategy sensibilities with autoregressive and moving average parameters at first, and with regard to lead-time and SMA parameters at second. Then, the authors make a comparative study with NIS and FIS strategies.

DDI Sensitivity With Regard to Autoregressive and Moving Average Orders and Coefficients

The authors first simulate $ARMA(p,q)$ demand models with different orders values $\left(p,q \in \{0,1,2,4,8\}^2\right)$ while maintaining causality and invertibility criteria's (ϕ_j and θ_j do not add up to one) and taking into account the uniqueness of demand processes (Zhang, 2004). In this first part of simulation, the authors calculate both MSE^{DDI} and $\tilde{I}_t^{DDI}$, for the following fixed parameters: $c = 10; \sigma_\xi^2 = 1; L = 5; N = 12; h=1; s = 2$. These parameters were randomly chosen but still similar to literature parameters to ensure comparability for future works.

Table 1. MSE^{DDI} and $\tilde{I}_t^{DDI}$ results for simulated $ARMA(p,q)$ demands

Model	Autoregressive Order p	Moving Average Order q	Autoregressive Coefficients ϕ_j	Moving Average Coefficients θ_j	MSE^{DDI}	$\tilde{I}_t^{DDI}$
1	1	0	$\phi_1 = 0.500$		26.7926	14.3894
2	1	0	$\phi_1 = 0.600$		36.5808	18.7090
3	0	1		$\theta_1 = 0.500$	18.5000	07.7789
4	0	1		$\theta_1 = 0.600$	20.9400	08,1536
5	1	1	$\phi_1 = 0.400$	$\theta_1 = 0.100$	24.2527	12.2041
6	1	1	$\phi_1 = 0.400$	$\theta_1 = 0.300$	33.2078	13.6816
7	1	2	$\phi_1 = 0.400$	$\theta_1 = 0.300$ $\theta_2 = 0.100$	37.4282	14.4392
8	1	2	$\phi_1 = 0.400$	$\theta_1 = 0.300$ $\theta_2 = 0.200$	42.0563	15.2594

continued on following page

Table 1. Continued

Model	Autoregressive Order p	Moving Average Order q	Autoregressive Coefficients ϕ_j	Moving Average Coefficients θ_j	MSE^{DDI}	$\tilde{I}_t^{DDI}$
9	1	4	$\phi_1 = 0.400$	$\theta_1 = 0.300$ $\theta_2 = 0.180$ $\theta_3 = 0.060$ $\theta_4 = 0.050$	44.6284	15.8453
10	2	1	$\phi_1 = 0.200$ $\phi_2 = 0.150$	$\theta_1 = 0.100$	19.6140	10.8756
11	4	1	$\phi_1 = 0.200$ $\phi_2 = 0.150$ $\phi_3 = 0.120$ $\phi_4 = 0.100$	$\theta_1 = 0.100$	24.1279	15.9735
12	4	2	$\phi_1 = 0.200$ $\phi_2 = 0.150$ $\phi_3 = 0.120$ $\phi_4 = 0.100$	$\theta_1 = 0.100$ $\theta_2 = 0.065$	26.5067	16.4101
13	8	1	$\phi_1 = 0.200$ $\phi_2 = -0.150$ $\phi_3 = 0.120$ $\phi_4 = -0.100$ $\phi_5 = 0.080$ $\phi_6 = 0.070$ $\phi_7 = 0.060$ $\phi_8 = -0.051$	$\theta_1 = 0.100$	12.8447	8.4158

Table 1 resumes results for simulating $ARMA(p,q)$ demand processes and calculating the producer's MSE^{DDI} and $\tilde{I}_t^{DDI}$, and this for $\phi_j \in [-1,1] \forall j = 1,..,p$ and $\theta_j \in [-1,1] \forall j = 1,..,q$. From the first two models of the table, when the demand parameters are fixed at $p = 1$ and $q = 0$, the authors can see that MSE^{DDI} and $\tilde{I}_t^{DDI}$ deteriorate on ϕ_1. This result coincides with the findings of Ali et *al.*, (2017) for an $AR(1)$ demand process. The same finding is made for the next two models of Table 1; MSE^{DDI} and $\tilde{I}_t^{DDI}$ deteriorate on θ_1 for an $MA(1)$ demand model. The percentage increase of the two indexes clearly differ on $AR(p)$ and $MA(q)$ models. Indeed, in simulation, when ϕ_1 increased from 0.5 to 0.6, MSE^{DDI} deteriorated by about 38% and $\tilde{I}_t^{DDI}$ by about 28%. Facing it, when θ_1 increased from 0.5 to 0.6, MSE^{DDI} deteriorated by about 11% and $\tilde{I}_t^{DDI}$ by about 5%. The AR and MA structures clearly influence MSE^{DDI} and $\tilde{I}_t^{DDI}$ results and so decision makers must take into account the structure of the demand as an important factor for improving their forecast.

Important comparison cases take place when the authors compare results for fixed p and variable q or vis versa. Intuitively, it was expected that, MSE^{DDI} and $\tilde{I}_t^{DDI}$ would increase on p for fixed q or on q for fixed p. Simulation proved that's not the case. Indeed, for example, the MSE^{DDI} and $\tilde{I}_t^{DDI}$ results, for the simulated $ARMA(8,1)$ in Table 1, are lower than $ARMA(1,1)$'s results. It concludes that MSE^{DDI} and $\tilde{I}_t^{DDI}$ would depend on ϕ_j's values $\forall j = 1,..,p$ and θ_j's values $\forall j = 1,..,q$ rather than autoregressive order p and moving average order q. Then, for all the rest of simulated $ARMA(p,q)$ demand processes (from model 5 to model 13), the authors found the same results as for $AR(1)$ and $MA(1)$ processes; i.e. for fixed orders p and q, MSE^{DDI} and $\tilde{I}_t^{DDI}$ deteriorates in a first way, as ϕ_i increase while maintaining $\left\{\phi_{\substack{j=1,..,p \\ j\neq i}}\right\}$ and $\left\{\theta_{j=1,..,q}\right\}$ having fixed values; or in a second way, deteriorates when θ_i increase while $\left\{\phi_{j=1,..,q}\right\}$ and $\left\{\theta_{\substack{j=1,..,q \\ j\neq i}}\right\}$ are fixed sets. This means that DDI performance depend on demand time-series structure, and especially would increase as demand is less auto-correlated to delayed demands and error terms. It would be interesting to study and mathematically generalize how the two performance metrics evolve with regard of ϕ_j and θ_j increase. Since this isn't a straightforward task, the authors plan to focus on this line for future work.

DDI Sensitivity With Regard to Lead-Time and SMA Parameters

The authors move on to study the stability of the two performance metrics behaviors with regard to N and L. For an $AR(1)$ demand process, Ali et *al*. (2017) showed that MSE^{DDI} improve on N and deteriorate on L. Table 2 presents the considered $ARMA(p,q)$ autoregressive and moving average coefficients for all the figures set. Here also, the authors simulated $ARMA(p,q)$ processes by considering ϕ_i and θ_j that do not add up to one and consider the following fixed parameters: $c = 10; \sigma_\xi^2 = 1; h=1; s = 2$.

Figures 1- 3 show the 3D-behavior of MSE^{DDI} and $\tilde{I}_t^{DDI}$ for different $ARMA(p,q)$ demand processes and for variable parameters L and $(L = 1,..,20 \;\&\; N = 1,..,20)$. Then, for each figure, the authors present (see Appendix) the projection on the first plan and the projection on the second plan. This is done for a better understanding and analysis of MSE^{DDI} and $\tilde{I}_t^{DDI}$ behaviors.

The figures set show the robustness of the typical behavior of MSE^{DDI} and $\tilde{I}_t^{DDI}$ performance metrics. For each fixed N, MSE^{DDI} and $\tilde{I}_t^{DDI}$ deteriorate on lead-time L. The authors note that the improve of MSE^{DDI} and $\tilde{I}_t^{DDI}$ on N is logarithmic, but the two performance metrics descent slopes are different. It means that, as it was noted in the literature, the percentage of amelioration in MSE^{DDI} and $\tilde{I}_t^{DDI}$ is different. Note also that these ameliorations differ for low and high values of N. For example, when we look at the projections on the first plan $(MSE \sim N)$, the point $N = 12$ can be considered as a threshold above which the MSE^{DDI} and $\tilde{I}_t^{DDI}$ ameliorations are not anymore important, in comparison with low values of N .where improvements are considerable.

From the projections on the second plans $(MSE \sim L)$, the authors note that the deterioration of MSE^{DDI} when the lead-time L increase, has an exponential shape. This exponential deteriorate is such important as N decrease. For $\tilde{I}_t^{DDI}$ level metric, the shape is logarithmic for high values of N and becomes linear for low values of N. These numerical findings confirm the theoretical analysis as MSE^{DDI} and $\tilde{I}_t^{DDI}$ are less sensible to L for higher values of N.

Table 2. Considered $ARMA(p,q)$ *Autoregressive & Moving Average coefficients*

Model	p	q	ϕ_i	θ_j
14	4	1	$\phi_1 = 0.25$ $\phi_2 = 0.2$ $\phi_3 = 0.12$ $\phi_4 = 0.09$	$\theta_1 = 0.2$
15	8	1	$\phi_1 = 0.25$ $\phi_2 = 0.2$ $\phi_3 = -0.12$ $\phi_4 = 0.09$ $\phi_5 = -0.08$ $\phi_6 = 0.07$ $\phi_7 = 0.06$ $\phi_8 = -0.051$	$\theta_1 = 0.2$
16	8	2	$\phi_1 = 0.25$ $\phi_2 = 0.2$ $\phi_3 = -0.12$ $\phi_4 = 0.09$ $\phi_5 = -0.08$ $\phi_6 = 0.07$ $\phi_7 = 0.06$ $\phi_8 = -0.051$	$\theta_1 = 0.2$ $\theta_2 = 0.15$

Figure 1. 3D plots of MSE^{DDI} *and* $\tilde{I}_t^{DDI}$ *behaviors under* $ARMA(4,1)$ *demand model*

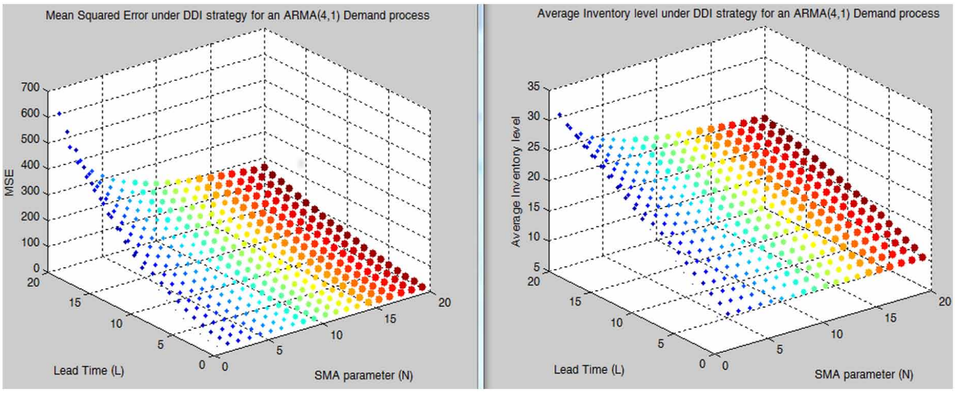

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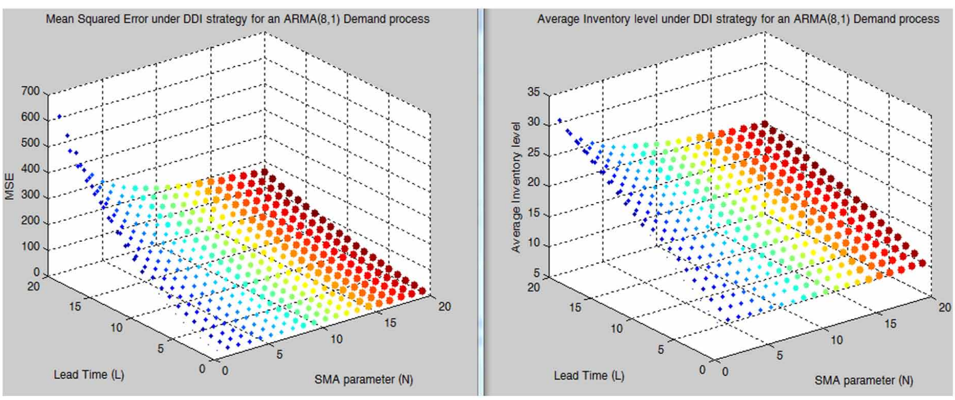
Figure 2. 3D plots of MSE^{DDI} *and* $\tilde{I}_t^{DDI}$ *behaviors under* $ARMA(8,1)$ *demand model*



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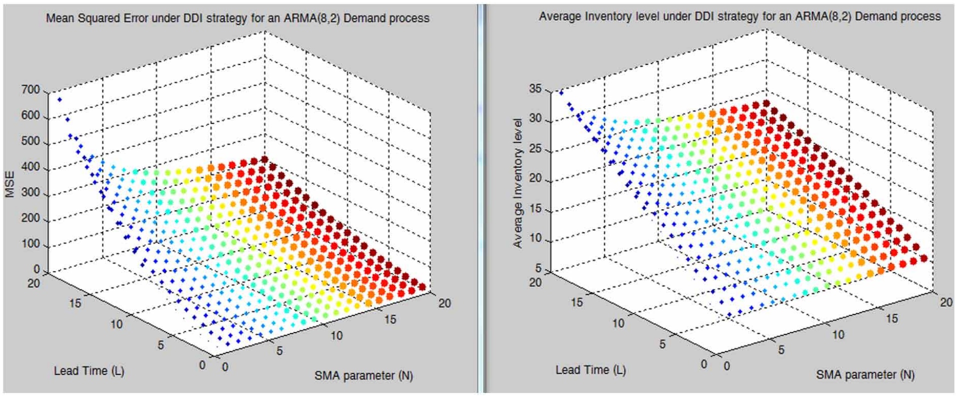
The authors conclude from this analysis that, for any causal invertible $ARMA(p,q)$ demand at the retailer, the producer's forecast will be more valuable in terms of MSE^{DDI} and $\tilde{I}_t^{DDI}$ when he uses higher values of SMA parameter N, and relatively lower values of lead-time L. This characterization is independent of demand's autoregressive order and moving average orders (p,q) and coefficients ϕ_i and θ_j.

Figure 3. 3D plots of MSE^{DDI} and $\tilde{I}_t^{DDI}$ behaviors under $ARMA(8,2)$ demand model



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DDI Strategy With Regard to NIS and FIS Strategies

For the comparative study, the researchers considered the same models simulated in Table 1 and the same fixed parameters: $c = 10; \sigma_\xi^2 = 1; L = 5; N = 12; h = 1; s = 2$. Then, the authors calculate each performance metric for the three strategies. The results of the simulations are shown in Table 3.

From the first look at Table. 3, the authors obtain the same evidence as previous researches. FIS outperforms both NIS and DDI in terms of MSE and $\tilde{I}_t$ and so, for any considered $ARMA(p,q)$ of demand process at the retailer. As discussed in Ali et *al*., (2017), on one hand, FIS outperforms NIS due to beneficial effects of information sharing. On the other hand, FIS outperforms DDI due to MMSE method accuracy which is more accurate than SMA method.

The authors then analyze the reported results in Table. 3 by considering the two first models. For an $AR(1)$ model such as considered in the work of Ali et *al*. (2017), the findings are similar. DDI strategy outperforms NIS for ϕ_1 large enough $(\phi_1 \in \{0.5, 0.6\})$ in the simulated models. Ali et *al*. (2017) illustrate the break-point from which DDI outperforms NIS, and which was evaluated at 0.24 for $L = 1$ and $N = 6$.

For demand models 3 and 4, the authors found that exceeds, despite exceeds . This finding is an expected result because, when the autoregressive order, and then the demand depending only on error terms, the optimal MMSE method outperforms the SMA method and then exceeds . As discussed in Ali et *al*. (2017), if the value

Table 3. Empirical MSE and $\tilde{I}_t$ results under the three considered strategies

Model	MSE^{NIS}	MSE^{DDI}	MSE^{FIS}	$\tilde{I}_t^{NIS}$	$\tilde{I}_t^{DDI}$	$\tilde{I}_t^{FIS}$
1	138.3996	26.7926	17.4580	33.0452	14.3894	11.1082
2	300.1029	36.5808	23.1328	62.3794	18.7090	13.6147
3	13.5000	18.5000	12.2500	8.5608	07.7789	6.3640
4	15.3600	20.9400	13.8000	9.3215	08,1536	6.4833
5	81.4330	24.2527	15.9216	23.0569	12.2041	9.5812
6	113.5408	33.2078	21.3956	31.7447	13.6816	9.9825
7	131.3007	37.4282	23.8242	37.0936	14.4392	10.0655
8	150.3507	42.0563	26.4134	43.2234	15.2594	10.1873
9	166.6726	44.6284	27.6609	48.7798	15.8453	9.9736
10	49.8496	19.6140	13.0142	17.7593	10.8756	8.5646
11	82.8049	24.1279	15.8459	34.5483	15.9735	11.6831
12	90.6387	26.5067	17.1084	37.3469	16.4101	11.6717
13	14.6534	12.8447	8.8315	10.3757	8.4158	6.9187

of the autoregressive coefficient is less than a certain breakpoint (in this case, in), the method effect overweight the bullwhip effect and so NIS is more valuable than DDI. The authors verify this result which stay valid for any demand models.

From model 5 to model 13 in Table. 3, the authors vary the autoregressive and moving average parameters p and q and for different $ARMA\left(p,q\right)$ models, MSE and $\tilde{I}_t$ kept the same behavior through the three strategies but the researchers note that percentage ameliorations are different between the two performance metrics. The authors estimate that it's not such important to find a break-point for each demand model, but still estimate that it would be more interesting to study and establish a general mathematical relation which allows to determine the break-point of any $ARMA\left(p,q\right), p > 0$ model with regard to L and N values. The authors are focusing on this aspect of contribution in our next work.

CONCLUSION

Over many years, the study of decentralized information structures has been one of the main research topics for academics and practitioners. The main issue of improving the overall performance of a global supply chain, where actors do not want or cannot share information, persists over time. As the economic structure begins to favor the integration of partners, the coordination of operational forecasts has proved effective in improving the performance of the supply chain and achieving near-optimal solutions, accepted by all stakeholders.

In a decentralized two-level supply chain consisting of a producer and retailer receiving end-customer demand, the authors study the robustness and consistency of a relatively new phenomenon called Downstream Demand Inference (DDI), in a context of generalized demand structure. This strategy allows an upstream actor to infer the demand arriving at his formal downstream actor who uses the Simple Moving Average (SMA) method in his prediction instead of using the optimal Minimum Mean Squared Error (MMSE) method. DDI allows the upstream actor to improve his Mean Squared Error (MSE) and Average Inventory level $\left(\tilde{I}_t\right)$, which can directly reduce the overall costs of the supply chain. DDI has recently been studied (Ali et *al.*, 2017), compared to two traditional demand management strategies and has proven its ability to improve supply chain performance. Most of the research was conducted under an $AR\left(1\right)$ demand model.

This chapter generalize MSE and $\tilde{I}_t$ expressions for invertible causal $ARMA\left(p,q\right)$ demand process under DDI strategy, No Information Sharing (NIS) and Forecast Information Sharing (FIS), and analyses the behavior of the two performance metrics with respect to Simple Moving Average (SMA) parameter N, lead-time L, demand's autoregressive order p and coefficients ϕ_i, and moving average order q and coefficients θ_j.

The authors first studied DDI sensitivity with regard to demand's autoregressive order p and coefficients ϕ_i, and moving average order q and coefficients θ_j. The chapter concludes that MSE^{DDI} and $\tilde{I}_t^{DDI}$ would depend on ϕ_j's values $\forall j = 1,..,p$ and θ_j's values $\forall j = 1,..,q$ rather than autoregressive order p and moving average order q. Indeed, MSE^{DDI} and $\tilde{I}_t^{DDI}$ deteriorates in a first way, as ϕ_i increase while maintaining $\left\{\phi_{\substack{j=1,..,p\\ j\neq i}}\right\}$ and $\left\{\theta_{j=1,..,q}\right\}$ having fixed values; or in a second way, producer's MSE^{DDI} and $\tilde{I}_t^{DDI}$ deteriorates when θ_i increase while $\left\{\phi_{j=1,..,q}\right\}$ and $\left\{\theta_{\substack{j=1,..,q\\ j\neq i}}\right\}$ are fixed sets. This means that DDI performance depend on demand time-series structure, and especially would increase as demand is less correlated to delayed demands and error terms.

The authors second studied DDI sensitivity with regard to lead-time L and SMA parameter N, and showed analytically and experimentally that MSE and $\tilde{I}_t$ under $ARMA(p,q)$ demand model, retain the same general behavior as an $AR(1)$. Indeed, for the totality of the simulated demand processes, MSE^{DDI} and $\tilde{I}_t^{DDI}$ positively depends on SMA order N and negatively on L, e.g. these two metrics improve as N increase or L decrease. The simulations show that the shape of the two performance metrics always develops in a logarithmically on N. Then, on one hand, authors found that MSE^{DDI} develops exponentially on L and this exponential deterioration is such important as N decrease. On the other hand, authors found that $\tilde{I}_t^{DDI}$ develops logarithmically on L and this logarithmic deterioration tend to be linear as N decrease. These findings mean that decision makers must exponentially increase the SMA parameter N in their forecast to reduce the deterioration effects caused by the increase of lead-time L, regardless of $ARMA(p,q)$ demand model.

The authors finally studied and compared DDI performance with NIS and FIS performance. For the simulations, the researchers found that FIS consistently outperforms DDI and NIS according to the $ARMA(p,q)$ demand model in terms of MSE and $\tilde{I}_t$ due to the benefits of information sharing. For the fixed parameters taken into account at the start of the simulations, the value of information sharing is indisputable and remains the optimal strategy for the supply chain actors. When the autoregressive order of the demand $p=0$, it was found that NIS is more valuable in terms of MSE than DDI as the precision of the method overweight the bullwhip effect when the demand is not auto-correlated to the delayed demands, but only to the terms of error. In terms of $\tilde{I}_t$, it was found that DDI outperforms NIS even when $p=0$. This finding could be interpreted by the non-translation of MSE into results. As mentioned by Boylan and Syntetos (2006), the results are the final measure to be taken into account, rather than the MSE. When the autoregressive order of demand $p>0$, it was found that DDI outperforms NIS for all the simulated demand processes. For different fixed parameters, it's relatively expected the same behavior of DDI in front of the NIS and FIS strategies, except the cases when method's accuracy and bullwhip effect are reversed.

The implication of these findings is relevant. Supply chain managers can introduce the use of the SMA forecast method into a more generalized $ARMA(p,q)$ demand model. This assumption is more realistic because, as seen above, the demand for a large number of products is auto-correlated over time, especially when decision-makers examine weekly or monthly datasets. Many incentive practices, as presented for information sharing (price reductions, buy-back or revenue sharing policies), may be proposed for the use of the SMA method.

The authors conclude the chapter with lines for future research. First, it would be interesting to study and mathematically generalize how the two performance metrics evolve with respect to the increase of autoregressive and moving average coefficients of demand process. Secondly, it's considered that it would be interesting to study and establish a general mathematical relation, which allows to determine the breaking point of any $ARMA\left(p,q\right), p > 0$ model, from which the DDI strategy is more valuable than the NIS strategy. Finally, this study can be further generalized to an $ARIMA\left(p,d,q\right)$ demand model.

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APPENDIX

Projections of MSE^{DDI} and $\tilde{I}_t^{DDI}$ Behaviors on the First and Second Plans

Figure 4. MSE^{DDI} *and* $\tilde{I}_t^{DDI}$ *first plan projection under* $ARMA(4,1)$ *demand model*

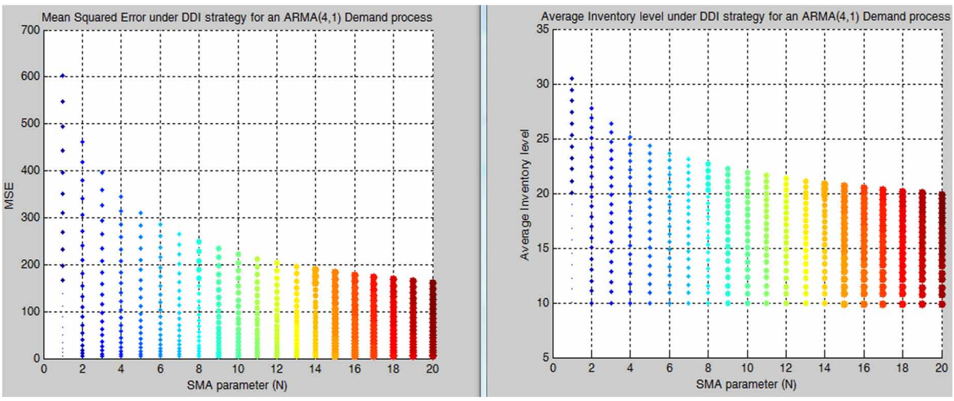

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Figure 5. MSE^{DDI} *and* $\tilde{I}_t^{DDI}$ *second plan projection under* $ARMA(4,1)$ *demand model*

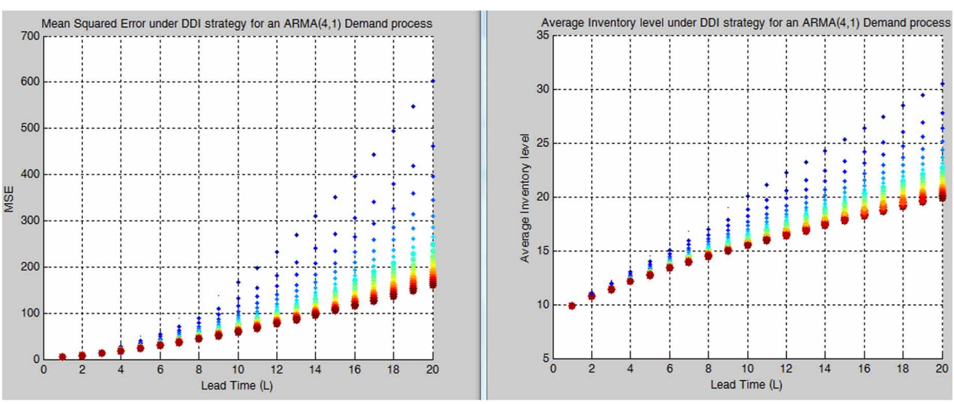

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Figure 6. MSE^{DDI} *and* $\tilde{I}_t^{DDI}$ *first plan projection under* $ARMA(8,1)$ *demand model*

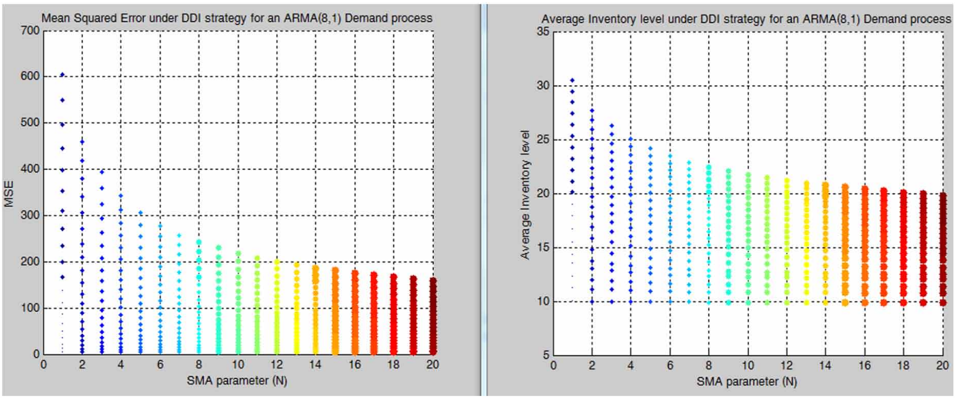

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Figure 7. MSE^{DDI} *and* $\tilde{I}_t^{DDI}$ *second plan projection under* $ARMA(8,1)$ *demand model*

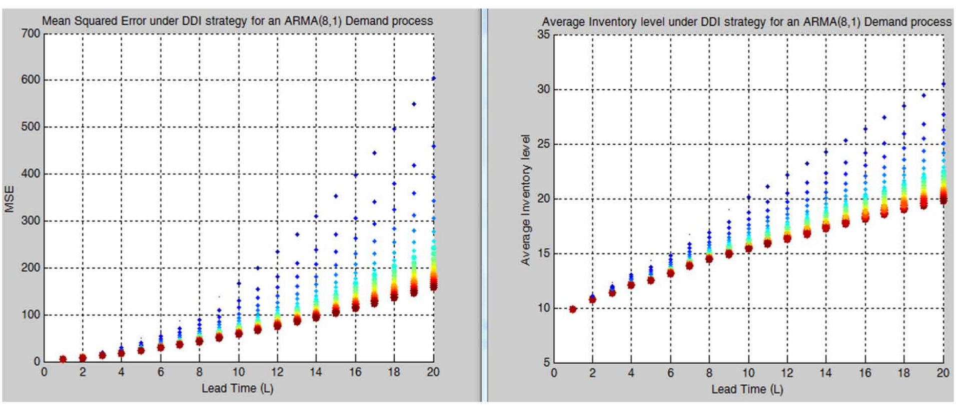

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Figure 8. MSE^{DDI} *and* $\tilde{I}_t^{DDI}$ *first plan projection under* $ARMA(8,2)$ *demand model*

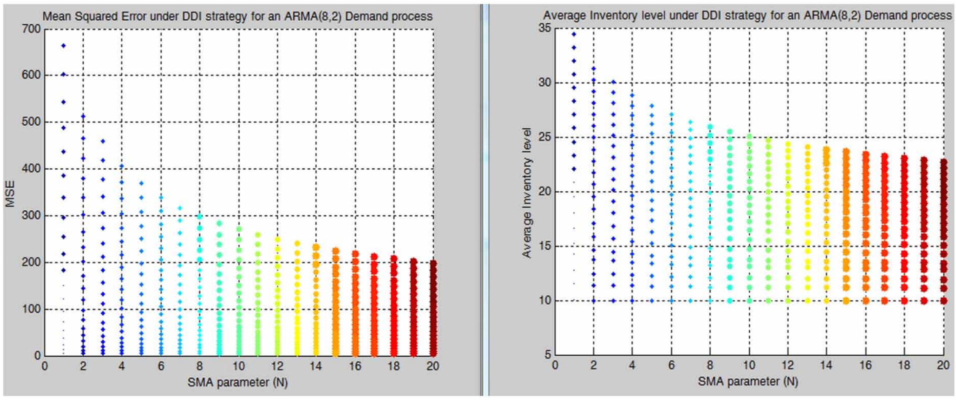

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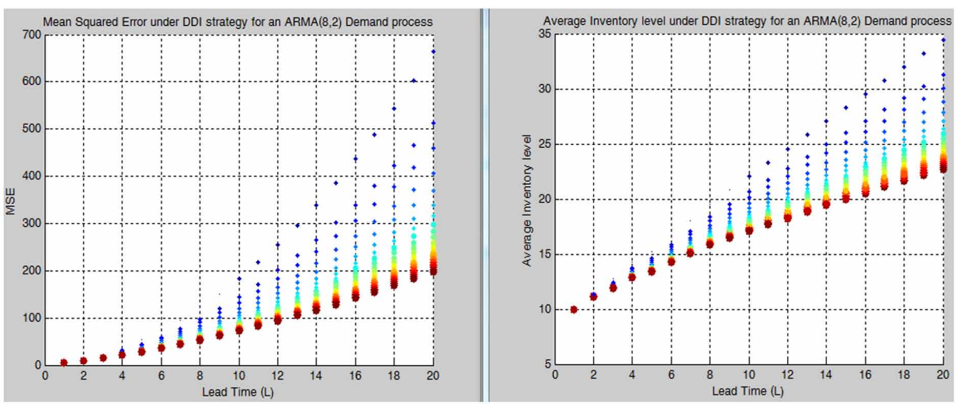
Figure 9. MSE^{DDI} *and* $\tilde{I}_t^{DDI}$ *second plan projection under* $ARMA(8,2)$ *demand model*



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Chapter 2
The Distribution and Pickup of Goods:
A Literature Review and Survey

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ABSTRACT

The literature of vehicle scheduling problems is rich with different approaches, which try to schedule the distribution of products to a network of clients. In this case, the vehicle routing problem with deliveries and pickups of goods is an extension of vehicle routing problem in which goods are transported from a depot (or multiple depots) to customers, as well from customers to the depots. There is tremendous work in the literature of this problem. Freight transport management deals with all distribution problems along the supply chain. This chapter presents a comprehensive review and survey of this literature. The literature is classified into four fundamental classes according to the way of the customers' visit and methods used for solving. Then different variants are generated according to the elements of the proposed framework. During this chapter, based on a proposed framework, the authors analyze the literature of the vehicle routing problem with deliveries and pickups, and as a result, the researchers propose a new classification where they give a short modeling of it.

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INTRODUCTION

The vehicle routing problem (VRP) is an important problem of goods distribution that concerns the design of routes from a depot to a set of customers geographically dispersed. The first authors, who studied this problem, were Dantzig and Ramser (1959). In their work, the authors study the question of the optimum routing of a fleet of gasoline delivery trucks between a bulk-terminal that supplies a large number of service stations. The shortest routes between any two points in the system are studied to minimize the total mileage covered by the fleet while satisfying the station demands. The authors proposed a procedure based on a linear programming formulation to obtain a near optimal solution.

From this year, different authors have studied the problem using combinatorial optimization and integer programming approaches to allocate a fleet of vehicles in order to service a number of customers. The proposed approaches can be applied in the fields of transportation, logistics & distributions.

The vehicle routing problem with collection and delivery (VRPCD) is an extension of vehicle routing problem (VRP) where the goods are transported from a depot (or multiple depots) to a set of customers, as well from a set of customers to the depots or other customers. The literature of the VRPCD is rich with an increasing number of approaches proposed during recent years considering different varieties, characteristics and assumptions proposed by authors. This recent problem can be applied in the distribution, for example in the beverage industry, as well as in the reverse logistics.

In order to classify the existing approaches of the vehicle routing problem with collection and delivery (VRPCD), in this paper based on a proposed framework of analysis, the literature of the VRPCD is classified into four fundamental classes according to the way of the customers' visits and methods used for solving them, then, different variants are generated according to the elements of the proposed framework. The remainder of this paper is organized as follow: section two to five present a description of the research methodology including our framework of analysis and an analysis of different characteristics and approaches of the literature. Section six provides a classification for vehicles routing problems with collections and deliveries. Section seven analyzes and describes methods of resolution and characteristics of problems treated. And finally, conclusions and directions for future research.

RESEARCH METHODOLOGY

In order to analyze our literature, authors have adapted the research methodology proposed by Taghipour & Frayrer (2013) to analyze the literature based on a proposed framework of analysis and using this framework to classify the contributions. To do this, in this research, the researchers focus on the vehicle routing literature dedicated to the pickup and delivery of goods. First, they analyze selected contributions of the literature using a systematic analysis based on several dimensions. Next, using this analysis, they propose a classification scheme of vehicle routing with pickup and delivery approaches based on their underlying methodological tools. In other words, the authors propose a classification that emphasizes the methods, rather than the decision models' characteristics or the VRP contexts. This allows them to analyze upfront the multidisciplinary nature of this domain of research (Taghipour & Frayret, 2013). This section outlines both the methodology used to identify and select contributions from the literature, and the systematic framework of analysis.

Identification of Contributions

In order to identify relevant contributions, several queries were used with the Compendex and web of knowledge databases. The main terms used in these queries are "pickup and delivery", "problems with backhauls", "problems with backhauling", "simultaneous pickup and delivery", "vehicle routing problem". More than 400 contributions were revealed, including journal papers, books and conference papers between 1989 and 2017. Then, from these 400 contributions, the researchers selected almost 101 references by considering different criteria in order to screen out contributions that are not relevant for this review, such as the contributions dealing with other variants of VRP.

More than 93% of these contributions are drawn in the last two decades. 77% of these references have been published between 2006 and 2017. 20% of papers have been published between 1995 and 2005, and less than 3% of these references have been published between 1989 and 1994.

FRAMEWORK OF ANALYSIS

Next, in order to investigate the specific structural and behavioural dimensions of the reviewed literature, this analysis focuses on two main criteria, which emphasizes the characteristics of the proposed approaches: Form of the problem and characteristic of routing approaches. As well, each main characteristic is divided into two sub characteristics as follow:

- Form of the problem (Network form, Demand type)
- Routing approach (Customer's visit, Methods)

Form of the network as well as type of demand specify the form of the problem, while way of visiting the customers as well as the mathematical method used to solve the problem specify the characteristics of routing approaches. Each of these sub-criteria is further sub-divided into several dimensions, as presented below.

Network Form

The network-form includes two main dimensions that are used to put into context the selected contributions, as it affects the complexity of the vehicle routing problem:

- **Number of Depots:** The simplest setup involves a single depot, from which the items can be delivered to different customers. As well, the multiple-depots is also considered the distribution nodes in some papers.
- **Route Forms:** Two forms of route are distinguishable: symmetric route versus asymmetric route. The symmetric version arises when the distance between each pair of nodes is the same in the two directions while the asymmetric occurs when the distance is not the same.

Demand Type

The next criterion that can affect the complexity of the problem is the demand type which includes two main dimensions:

- **Certainty:** This includes two types of demand. The deterministic demand and stochastic demand. A stochastic demand is an anticipated demand including its variation.
- **Dynamism:** Which comprises dynamic and static demand. Dynamic demand is change during planning horizon while a static demand is fixed during routing problem.

Customers' Visits

Visiting the customers depend on different factors including the number of vehicles, the presence of the time constraint, the number of products and the selected way to visit customers. Following, the authors explain the components of each factor.

- **Number and Types of Vehicles:** The routing problem can be solved using single or multiple vehicles distributing the products from the depots to the customers. In the case of multiple vehicles, two possible distinguishes are homogeneous and heterogeneous vehicles.
- **Types of Product:** Routing problem can be subject to the delivery of single type of product or the distribution of multiple types of product.
- **Time Constraint:** The existence or nonexistence of the constraint of time is other aspect that can affect the complexity of the problem.
- **Priority of Visit:** The literature can be divided based on the attention given to deliveries, pickups, both of deliveries and pickups and finally any sequence of visit.

Methods

Generally, the present approaches are based on two major methods: exact versus approximate methods. These methods respectively can be categorized into some other techniques. Table 1 provide readers with these methods and techniques.

ANALYSIS

Using this framework of analysis, each reference was analyzed according to four presented dimensions. The results of this analysis are reported in Tables two to four. This section analyses each dimension individually.

Table 1. Classification of methods used for solving the VRPCD

<table>
<tr><th rowspan="3">Exact Methods</th><th colspan="5">Approximate Methods</th></tr>
<tr><th colspan="2">Classical (Simple) Heuristics</th><th colspan="3">Metaheuristics and Hybridization</th></tr>
<tr><th>Constructive</th><th>Improvement</th><th>Local Search</th><th>Population-Based Search</th><th>Learning Mechanisms</th></tr>
<tr><td>• Branch and bound
• Branch and cut
• Branch and price
• Set partitioning formulations</td><td>• Clarke and wright saving algorithm
• Sweep algorithm
• Fisher and Jaikumar algorithm
• Route first-cluster second</td><td>• Inter-route and intra-route exchanges
• 2 and 3-opt move
• Insertion</td><td>• Tabu search
• Simulated annealing
• Variable neighborhood search</td><td>• Genetic algorithm
• Memetic algorithm</td><td>• Neural networks optimization
• Ant colony optimisation</td></tr>
</table>

Form of the Problem: Network Form and Demand

Concerning the form of the problem, the most common forms studied concerns: the problems with a single depot covering symmetric distances and in the deterministic and static environment. Among the studied papers, only 7% considers the problem with multiple depots. No author has studied the problem under asymmetric distances. 9% of papers deal with stochastic demands and only 5% of the papers focuses on dynamic environment (Table 2).

Table 2. Form of the problem: network form and demand

Year	Authors	Form of the Problem			
		Network Form		Demand	
		Depot Single/ Multiple	Distance Symmetric/ Asymmetric	Certainty Deterministic/ Stochastic	Dynamism Static/ Dynamic
1989	Goetschalckx & Jacobs-Blecha	Single	Symmetric	Deterministic	Static
1991	Dumas et al.	Single	Symmetric	Deterministic	Static
1995	Gélinas et al.	Single	Symmetric	Deterministic	Static
1996	Gendreau et al.	Single	Symmetric	Deterministic	Static
1996	Thangiah et al.	Single	Symmetric	Deterministic	Static
1997	Duhamel et al.	Single	Symmetric	Deterministic	Static
1997	Toth and Vigo	Single	Symmetric	Deterministic	Static
1998	Mosheiov	Single	Symmetric	Deterministic	Static
1999	Mingozzi et al.	Single	Symmetric	Deterministic	Static
1999	Salhi and Nagy	Single	Symmetric	Deterministic	Static
2000	Jung and Haghani	Single	Symmetric	Deterministic	Static
2000	Nanry and Barnes	Single	Symmetric	Deterministic	Static
2001	Dethloff	Single	Symmetric	Deterministic	Static
2006	Bent and Van Hentenryck	Single/Mu.	Symmetric	Deterministic/ St	Static/Dyn.
2006	Brandao	Single	Symmetric/ Asy.	Deterministic	Static
2006	Chen and Wu	Single	Symmetric	Deterministic	Static
2006	Dell'Amico et al.	Single	Symmetric	Deterministic	Static
2006	Fabri and Recht	Single	Symmetric	Stochastic	Dynamic
2006	Gendreau et al.	Single	Symmetric	Deterministic	Dynamic

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Table 2. Continued

Year	Authors	Form of the Problem			
		Network Form		Demand	
		Depot Single/ Multiple	Distance Symmetric/ Asymmetric	Certainty Deterministic/ Stochastic	Dynamism Static/ Dynamic
2006	Ghaziri and Osman	Single	Symmetric	Deterministic	Static
2008	Zhang et al.	Single	Symmetric	Deterministic	Static
2009	Cortés et al.	Single	Symmetric	Stochastic	Dynamic
2009	Deng et al.	Single	Symmetric	Deterministic	Static
2010	Hou and Zhou	Single	Symmetric	Stochastic	Dynamic
2010	Mingyong and Erbao	Single	Symmetric	Deterministic	Static
2011	Lin	Single	Symmetric	Deterministic	Static
2011	Minis and Tatarakis	Single	Symmetric	Stochastic	Static
2012	Anbuudayasankar et al.	Single	Symmetric	Deterministic	Static
2012	Karaoglan et al.	Multiple	Symmetric	Deterministic	Static
2014	Palhazi Cuervo et al.	Single	Symmetric	Deterministic	Static
2014	Rieck et al	Multiple	Symmetric	Stochastic	Dynamic
2014	Tajik et al.	Single	Symmetric	Stochastic	Static
2014	Vincent and Lin	Multiple	Symmetric	Deterministic	Static
2015	Dimitrakos and Kyriakidis	Single	Symmetric	Stochastic	Static
2015	García-Nájera et al.	Single	Symmetric	Deterministic	Static
2015	Heng et al.	Single	Symmetric	Deterministic	Static
2015	Kachitvichyanukul et al.	Multiple	Symmetric	Deterministic	Static
2015	Karaoglan and Altiparmak	Multiple	Symmetric	Deterministic	Static
2015	Wang et al.	Single	Symmetric	Dter./ Stochastic	Static
2015	Yalcın and Erginel	Single	Symmetric	Deterministic	Static
2016	Ghilas et al.	Multiple	Symmetric	Stochastic	Static
2016	Oesterle and Bauernhansl	Single	Symmetric	Deterministic	Static
2016	Wassan et al.	Single	Symmetric	Deterministic	Static
2016	Wu et al.	Single	Symmetric	Deterministic	Static
2017	Veenstra et al. a	Single	Symmetric	Deterministic	Static
2017	Veenstra et al. b	Single	Symmetric	Deterministic	Static

Routing Approach: Customers' Visits

The two parts of the routing approach is analyzed separately. In the customers' visits, the most common elements studied concerns: the problems with multiple homogeneous vehicles prioritizing picking single product without the time constraint. Among the studied papers, only 10% of the papers considers the problem using heterogeneous vehicles. 9% of papers considers the problem with multiple product and 61% of the papers does not consider the time constraint in problem resolution. Finally, the author most (33% of the papers) gives first the priority to pickups. 28% of papers gives the same degree of priority to deliveries and pickups. 26% of papers gives the first the priority to deliveries and 19% of papers does not consider any priorities (Table 3).

Table 3. Routing approach: customers' visits

Year	Authors	Routing Approach			
		Customers' Visit			
		Number and Types of Vehicles Single/ Multiple (Homogenous/ Heterogenous)	Types of Product Single/ Multiple	Time Constraint With/ Without	Priority of Visit Deliveries/ Pickups/ Both/ Any Sequence
1989	Goetschalckx & Jacobs-Blecha	Homogenous	Single	With	Deliveries
1991	Dumas et al.	Homogenous	Single	With	Pickups
1995	Gélinas et al.	Homogenous	Single	With	Deliveries
1996	Gendreau et al.	Single	Single	Without	Deliveries
1998	Mosheiov	Single, Homo.	Single	Without	Any
1999	Mingozzi et al.	Homogenous	Single	Without	Deliveries
2002	Osman and Wassan	Homogenous	Single	Without	Deliveries
2002	Wade and Salhi	Homogenous	Single	Without	Any
2003	Cheung and Hang	Heterogenous	Single	With	Pickups
2003	Li and Lim	Homogenous	Single	With	Pickups
2003	Süral and Bookbinder	Single	Single	Without	Any

continued on following page

Table 3. Continued

Year	Authors	Routing Approach			
		Customers' Visit			
		Number and Types of Vehicles Single/ Multiple (Homogenous/ Heterogenous)	Types of Product Single/ Multiple	Time Constraint With/ Without	Priority of Visit Deliveries/ Pickups/ Both/ Any Sequence
2004	Hernández & Salazar-González	Single	Single	Without	Pickups
2006	Tavakkoli-Moghaddam et al.	Heterogenous	Single	Without	Deliveries
2007	Bianchessi and Righini	Homogenous	Single	Without	Both
2007	Ropke et al.	Homogenous	Single	With	Pickups
2008	Gribkovskaia et al.	Single	Single	Without	Both
2008	Lin	Heterogenous	Single	With	Pickups
2009	Zhao et al.	Single	Single	Without	Pickups
2010	Hou and Zhou	Homogenous	Single	Without	Both
2010	Mingyong and Erbao	Heterogenous	Single	With	Both
2011	Lin	Homogenous	Multiple	With	Pickups
2011	Minis and Tatarakis	Single	Single	Without	Any/ Both
2013	Goksal et al.	Homogenous	Single	Without	Any/ Both
2013	Liu et al.	Homogenous	Single	With	Both
2013	Salhi et al.	Heterogenous	Single	Without	Deliveries
2014	Palhazi Cuervo et al.	Homogenous	Single	Without	Deliveries
2014	Rieck et al	Homogenous	Multiple	Without	Pickups
2014	Tajik et al.	Homogenous	Single	With	Pickups
2016	Avci and Topaloglu	Heterogeneous	Single	Without	Pickups
2016	Ho and Szeto	Single	Single	Without	Pickups
2016	Iassinovskaia et al.	Homogeneous	Single	Without	Both
2016	Kalayci and Kaya	Homogeneous	Single	Without	Both

continued on following page

Table 3. Continued

Year	Authors	Routing Approach			
		Customers' Visit			
		Number and Types of Vehicles Single/ Multiple (Homogenous/ Heterogenous)	Types of Product Single/ Multiple	Time Constraint With/ Without	Priority of Visit Deliveries/ Pickups/ Both/ Any Sequence
2016	Li et al.	Homogenous	Single	With	Pickups
2016	Männel and Bortfeldt	Homogenous	Multiple	Without	Pickups
2016	Oesterle and Bauernhansl	Heterogenous	Single	With	Any
2016	Wassan et al.	Homogeneous	Single	Without	Deliveries
2016	Wu et al.	Heterogeneous	Single	With	Any
2017	Veenstra et al.	Homogeneous	Multiple	Without	Pickups
2017	Veenstra et al. b	Single	Single	Without	Pickups

Routing Approach: Proposed Methods

In the part of the proposed methods of routing approach, the most common main method used in the resolution is metaheuristics and hybridization with 68% of the total papers. The application of exact and heuristic methods is limited to near 15% (Table 4).

DISCUSSION

Concerning the characteristics of the methods proposed in the literature, this analysis highlights the fact that most approaches are based on meta-heuristic mechanisms of exploration of the solution space. In other words, most methods do not aim at finding an optimal solution. This lack of formal exact methods may be related to the size of problems that can limit achieving to an optimal solution. So, this lack of exact methods remains an opportunity to develop further near optimal exploration of the solution space.

Table 4. Routing approach: proposed method

Year	Authors	Routing Approach	
		Proposed Method	
		Name	Types of Method Exact(E)/ Heuristic(H)/ Meta-heuristic & Hybridization (MH)
1989	Goetschalckx & Jacobs-Blecha	Space filling curve heuristic & exchange improvement procedures	H
1991	Dumas et al.	Algorithm using column generation with a constrained shortest path as a subproblem	E
1995	Gélinas et al.	Branching strategy (column generation)	E
1996	Gendreau et al.	Near optimal heuristic (six heuristic)	MH
1996	Potvin et al.	Genetic algorithm	MH
1996	Thangiah et al.	Local search heuristic	MH
1997	Duhamel et al.	Tabu search	MH
1997	Toth and Vigo	Branch & bound (lagrangian lower bound strengthened	E
1998	Mosheiov	Tour partitioning heuristic	H
1999	Mingozzi et al.	HDS & EHP procedures	E
1999	Salhi and Nagy	Cluster insertion heuristic	H
2000	Jung and Haghani	Genetic algorithm	MH
2000	Nanry and Barnes	Reactive tabu search	MH
2001	Dethloff	Constructive heuristic based on cheapest insertion, radial surcharge and residual capacity	H
2003	Süral and Bookbinder	Miller trucker zemlin sub-tour	E
2004	Hernández & Salazar-González	Branch & cut algorithm based on a new 0-1 ILP model	E

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Table 4. Continued

Year	Authors	Routing Approach	
		Proposed Method	
		Name	Types of Method Exact(E)/ Heuristic(H)/ Meta-heuristic & Hybridization (MH)
2004	Mitrović-Minić et al.	Double horizon based heuristic (cheapest insertion procedure & tabu search)	MH
2005	Crispim and Brandao	Tabu algorithm & variable neighborhood decent	MH
2005	Mitra	Construction heuristic	H
2005	Zhong and Cole	Guided local search	MH
2006	Bent and Van Hentenryck	Simulated annealing algorithm with large neighborhood search	MH
2006	Brandao	New tabu search	MH
2006	Chen and Wu	Tabu lists & route improvement procedures	MH
2006	Dell'Amico et al.	Branch & price based on dynamic programming & state space relaxation	E
2008	Zhang et al.	Ant colony system with the pheromone updating strategy of ASRank & MMAS ant algorithm	MH
2009	Çatay	Ant colony optimization	MH
2009	Chunyu and Xiaobo	Hybrid generic algorithm	MH
2009	Cortés et al.	Adaptive predictive based on particle swarm optimization	MH
2009	Deng et al.	Improved simulated annealing	MH
2009	Gutiérrez-Jarpa et al.	Branch & cut	E
2009	Liu and Chung	Variable neighborhood tabeau search	H
2009	Tütüncü et al.	Greedy randomized adaptive memory programming search	MH
2009	Zhao et al.	Genetic algorithm	MH

continued on following page

Table 4. Continued

Year	Authors	Routing Approach	
		Proposed Method	
		Name	Types of Method Exact(E)/ Heuristic(H)/ Meta-heuristic & Hybridization (MH)
2010	Hou and Zhou	Improved genetic algorithm	MH
2010	Mingyong and Erbao	Improved differential evolution algorithm	MH
2011	Lin	Two stage heurisctic	H
2011	Minis and Tatarakis	Dynamic programming algorithm	E
2012	Anbuudayasankar et al.	Genetic algorithm & modified saving heuristic	MH
2012	Karaoglan et al.	Two phase heuristic based on simulated annealing	MH
2012	Kassem and Chen	Classical heuristics (insertion based heuristic)	H
2012	Zachariadis and Kiranoudis	Local search algorithm	H
2013	Salhi et al.	Set partitioning based heuristic	H
2014	Zhang et al.	Ant colony system with tabu search	MH
2015	Avci and Topaloglu	Adaptive local search algorithm (simulated annealing with variable neighborhood)	MH
2015	Yalcın and Erginel	Fuzzy multi objective programming (clustring, routing and local search)	MH
2016	Avci and Topaloglu	Adaptive local search algorithm (Simulated Annealing with Variable Neighborhood)	MH
2016	Li et al.	Adaprive large neighborhood search	MH
2016	Männel and Bortfeldt	Large neighborhood search and a tree search heuristic	MH

continued on following page

Table 4. Continued

Year	Authors	Routing Approach	
		Proposed Method	
		Name	Types of Method Exact(E)/ Heuristic(H)/ Meta-heuristic & Hybridization (MH)
2016	Oesterle and Bauernhansl	Exact method based on clustering	E
2016	Wassan et al.	Reactive tabu search	MH
2016	Wu et al.	Multi-attribute label-based Ant Colony System (LACS) algorithm	MH
2017	Veenstra et al.	Branch-price- and-cut algorithm a labeling algorithms	E/MH
2017	Veenstra et al. b	Large neighborhood search (LNS)	MH

CLASSIFICATION OF ROUTING APPROACHES

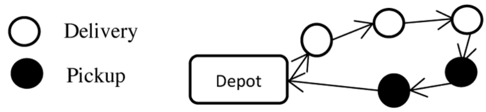
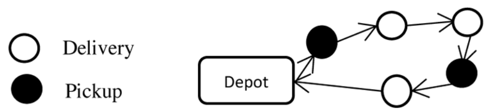
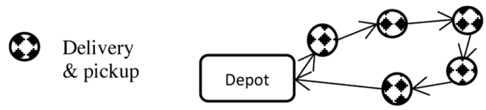
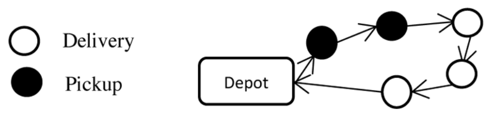
This analysis of the literature highlights the general aspects of vehicle routing contributions with deliveries and pickups. These contributions are built their approaches based on different exact or approximate algorithm to route or schedule a fleet of vehicles to traverse between a set of customers to deliver and pick-up a set of products. Using different characteristics, different variants of these approaches are proposed in the literature. This section proposes a classification of these different approaches, according to their underlying methodological algorithm of routing (Table 5).

This classification scheme includes four main classes of general approaches and different sub-classes are proposed based on the form of problem and the routing approach analyzed previously (Table 6).

Problems With Deliveries Made Before All Pickups (PDBP)

In this category of problems, all deliveries must be made before any pickups on each route. Regarding the methods used to solve the problem, three main sub-classes are distinguished in this class are respectively: exact methods for problems in

Table 5. Main classes of routing approaches

Main Class	Explanation	Schematic Example
Problems with deliveries made before all pickups (PDBP)	All deliveries must be made before any pickups on each route.	
Problems with delivery and pickup occur in any sequence (PDPAS)	The deliveries and backhauls may occur in any sequence on a vehicle tour.	
Problems with deliveries and pickups made at the same stop (PDPSS)	A set of customers is geographically dispersed, each customer requires both of a delivery and pick-up operation.	
Problems with pickup and delivery starting by pickup load (PPDSP)	All pickups must be made before any delivery on each route.	

which deliveries made before all pickups (PDBP); classical heuristics methods and metaheuristic and hybridization methods. Considering different form of the problem.

Exact Methods

The exact resolution methods ensure obtaining an optimal solution of the problems. These methods are used to solve small problems where the number of possible combinations is quite low. There exist a limited number of works in the literature using exact methods for solving the problems in which deliveries are made before any pickup load and that because these problems are classified NP-hard (according to complexity theory).

(Toth and Vigo, 1997) have treated the symmetric and asymmetric vehicle routing problem with backhauls in a consolidated framework. The symmetric version arises when the distance between each pair of nodes is the same in the two directions while the asymmetric occurs when the distance is not the same. For this problem they proposed an integer linear programming model and Lagrangian lower bound obtained by the branch and bound algorithm is also combined with a lower bound obtained by dropping the capacity constraints to obtain an effective overall bounding procedure.

Classical Heuristics Methods

A heuristic is defined by (Reeves, 1995) as a technique that seeks good solutions (quasi-optimal) for a cost of reasonable calculation without being able to guarantee optimality. The precedence of deliveries in the vehicle routing problem with backhauls is treated by a bit of classical heuristics methods.

(Goetschalckx and Jacob-Blecha, 1989) have proposed a two-phased solution methodology, where in the first phase, a solution is generated based on space filling curve heuristic and in the second phase, this solution is improved using exchange improvement procedures. They considered that the fleet of vehicles is homogeneous and there are no time windows when visiting customers.

Metaheuristic and Hybridization Methods

The Metaheuristics try to find the global optimum of a difficult optimization problem without being trapped by local optima. These are a top-level general strategy which guides other heuristics to search for feasible solutions in domains where the resolution is hard. There is a huge works in the literature that used metaheuristics or hybridization for problems in which deliveries made before all pickups. According to the different features, many variants of this problem are generated. The first variant is characterized by homogeneous fleet of vehicles, single depot, single product, symmetric distance, static environment, deterministic demand, and time constraint (PDBP-HSSSSDT). Second extension contains problems in which deliveries are made before all pickups load with homogeneous fleet of vehicles, single depot, single product, symmetric distance, static environment and deterministic demand (PDBP-HSSSSD). The third variant is the set of problems with heterogeneous fleet of vehicle, single depot, single product, symmetric and asymmetric distance, static environment and deterministic demand (PDBP-HESSSASD). Another variant named (PDBP-HEMSSSD) that has the same features of PDBP-HESSSASD just the number of depots is different, where it uses multi-depots and symmetric distance.

Problems With Delivery and Pickup Occur in Any Sequence (PDPAS)

Problem without precedence of delivery is a problem denotes the fact that deliveries and backhauls may occur in any sequence on a vehicle tour. Regarding the methodes used to solve the problem, three main sub-classes are distinguished in this class are respectively: exact methods; classical heuristics methods and metaheuristic and hybridization methods for problems with deliveries made before all pickup

Exact Methods

(Süral and Bookbinder, 2003a) developed a mixed-integer model based on Miller-Tucker-Zemlin (MTZ) sub-tour elimination constraints for the vehicle routing problem without precedence of backhauls. Authors treated this problem in case of one vehicle used and the choice of the best of the backhauls customers, depending on the revenue generated. They concluded that for almost 75% of test problems is optimally solved in a reasonable computation time using a general purpose commercial solver.

Classical Heuristics Methods

(Mosheiov, 1998) proposed two heuristics of a tour partitioning for solving vehicle routing problem with pickup and delivery, where all deliveries occur between the depot and customers' locations. This method consists of constructing a traveling salesman tour through all customers (basic tour), then the tour partitioning (TP) heuristic breaks this tour into disjoint segments, such that each path (segment) contains only a limit number of customers that respect the constraint of capacity and connects the end points of each path to the depot. These operations are repeated for searching the best solutions until reaching the max number of iterations through the iterated tour partitioning (ITP) heuristic. Author also tested the problem formulation for the case of single vehicle by a LINDO program, where only problems of up 12 customers were solved.

Metaheuristic and Hybridization Methods

Different approaches are proposed as metaheuristic and hybridization methods for problems with delivery and pickup occur in any sequence. The first class is the set of problems that pickup and delivery occur in any sequence with heterogeneous fleet of vehicles, single depot, single product, symmetric distance, static environment, deterministic demand, and time windows (PDPAS-HESSSSDT). Another variant that uses homogeneous fleet of vehicles, single depot, single product, symmetric distance and static environment and deterministic demand (PDPAS-HSSSSD). Third variant is studied in this class which uses a homogeneous fleet of vehicles, multi-depots, single product, symmetric distance, static environment and deterministic demand (PDPAS-HMSSSD).

Problems With Deliveries and Pickups Made at the Same Stop (PDPSS)

For problems in which delivery and pickup are made at the same stop, a set of customers is geographically dispersed, each customer requires both of a delivery and pick-up operation. Regarding the methodes used to solve the problem, three main sub-classes are distinguished in this class are respectively: exact methods; classical heuristics methods and metaheuristic and hybridization methods.

Exact Methods

(Angelelli and Mansini, 2002) are the first using exact algorithms for the vehicle routing problem with simultaneous delivery and pickup and time windows. They implemented a branch and price approach based on a set covering formulation for the master problem where they used a relaxation of the elementary shortest path problem with time windows and capacity constraints as pricing problem. For the experimental analysis, known benchmarks instances for VRPTW have been modified.

Classical Heuristics Methods

(Dethloff, 2001a) developed a mathematical formulation for vehicle routing problem with simultaneous pickup and delivery and he proposed a constructive heuristic based on cheapest insertion, radial surcharge, and residual capacity to solve it.

Metaheuristic and Hybridization Methods

Authors have proposed different metaheuristics and also hybridization for the vehicle routing problem where the deliveries and pickups done at the same stop. Like the other classes of problems, problems in which pickup and delivery are made at the same stop has different variants.

The first extension (variant) is the set of problems with deliveries and pickups made at the same stop with homogeneous fleet of vehicles, single depot, single product, symmetric distance, static environment and deterministic demand (PDPSS-HSSSSD). The second extension is the set of problems with homogeneous fleet of vehicles, single depot, single product, symmetric distance, static environment, deterministic demand and time windows (PDPSS-HSSSSDT). There are two other variants that uses single vehicle. In the first we have single depot, single product, symmetric distance, static environment and deterministic demand (PDPSS-SSSSSD). In the second, we have multi-depots, single product, symmetric distance, static environment and stochastic demand (PDPSS-SSMSSS). In the literature, a new variant has appeared uses a heterogeneous fleet of vehicles, single depot, single product, symmetric distance, static environment and deterministic demand (PDPSS-HESSSSD). Another variant exist that uses homogeneous fleet of vehicles, single depot, single product, symmetric distance, dynamic environment and stochastic demand (PDPSS-HSSSDS). For the use of multiple depots, there are a variant that considers homogeneous fleet, multiple depots, single product, symmetric distance, static environment and deterministic demand which named (PDPSS-HMSSSD).

Problems With Pickup and Delivery Starting by Pickup Load (PPDSP)

Regarding the methodes used to solve the problem, three main sub-classes are distinguished in this class are respectively: exact methods; classical heuristics methods and metaheuristic and hybridization methods.

Exact Methods

(Hernández-Pérez and Salazar-González, 2004) introduced a branch and cut algorithm based on a new 0-1 ILP model for a travelling salesman problem with pickup and delivery. Experimental results proved the effectiveness of the proposed method for solving the travelling salesman problem with pickup and delivery (TSPPD).

Classical Heuristic Methods

(Lin, 2011a) developed a mixed integer program for a vehicle routing problem with pickup and delivery in which two different resources are used to transport the heavy and light customers' items. Then, a two –stage heuristic using exact approaches and an ejection chain based on modifying the shortest path algorithm. Authors generated two initial solutions using a relaxation version and a simplified version of the mixed integer program. This method using coordination strategy was compared with others methods with an independent strategy and a partial coordination strategy for problems up to 200 customers, where in terms of lower average total cost and usage of heavy resource, the benefit of coordination was realized over the independent strategy.

Metaheuristic and Hybridization Methods

Many metaheuristic and hybridization methods are proposed for different variants of the problem with pickup and delivery that starts by pickup load. According the literature, we distinguished eight variants for last sub-class as follow: homogeneous fleet of vehicles, single depot, single product, symmetric distance, static environment, deterministic demand and with time constraint (PPDSP-HSSSSDT); heterogeneous fleet of vehicles, single depot, single product, symmetric distance, static environment, deterministic demand and with time constraint (PPDSP-HESSSDT); homogeneous fleet of vehicles, single depot, single product, symmetric distance, dynamic environment and stochastic demand (PPDSP-HSSSDS); homogeneous fleet of vehicles multiple depots, multiple products, symmetric distance, dynamic environment and stochastic demand (PPDSP-HMMSDS); homogeneous fleet of vehicles, single depot, single product, symmetric distance, dynamic environment, stochastic demand and time constraint (PPDSP-HSSSDST); homogeneous fleet of vehicles, single depot, multi-products, symmetric distance, static environment and deterministic demand (PPDSP-HSMSSD); single vehicle, single depot, single product, symmetric distance and static environment and deterministic demand (PPDSP-SSSSSD); homogeneous fleet, multiple depots, single product, symmetric distance, static environment, deterministic demand and time constraint (PPDSP-HMSSSDT).

Works That Combine Two Classes at the Same Time

There are some works that combine two classes at the same time as follow. Some authors like (Zhong and Cole, 2005) presented works that deal with both problems with deliveries made before all pickups and problems with delivery and pickup may occur in any sequence. They have proposed a guided local search for pickup and delivery problem with and without precedence of delivery. They considered a time constraint for each visit of customer. Computational results proved that some of the results found were better than those in the literature.

ANALYSIS AND DESCRIPTION

In this part, we will compare between the master classes, methods used for each class, and between variants in each master class.

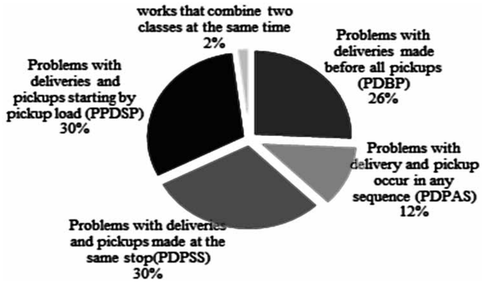
Comparison Between the Four Master Classes

According to the survey made in this study, we compared the percentage of works for each class to discover the most and least studied classes in the problem with pickup and delivery of goods.

Table 6. Variants in meta-heuristic and hybridization

Main Class	Variants in Meta-heuristic and Hybridization
Problems with deliveries made before all pickups (PDBP)	HSSSSDT: Homogeneous vehicles, Single depot, Single product, Symmetric distance, Static environment, Deterministic demand and Time constraint. HSSSSD: Homogeneous vehicles, Single depot, Single product, Symmetric distance, Static environment and Deterministic demand. HESSSASD: heterogeneous, Single depot, Single product, Symmetric, Asymmetric distance, Static environment and Deterministic demand. HEMSSSD: Heterogeneous vehicles, Multiple depot, Single product, Symmetric distance, Static environment and deterministic demand.
Problems with delivery and pickup occur in any sequence (PDPAS)	HESSSSDT: Heterogeneous vehicles, Single depot, Single product, Symmetric distance, Static environment, Deterministic demand and Time constraint HSSSSD: Homogeneous vehicles, Single depot, Single product, Symmetric distance, static environment and Deterministic demand. (HMSSSD: Homogeneous vehicles, Multiple depot, Single product, Symmetric distance, Static environment and Deterministic demand.
Problems with deliveries and pickups made at the same stop (PDPSS)	HSSSSD: Homogeneous vehicles, Single depot, Single product, Symmetric distance, Static environment and Deterministic demand. HSSSSDT: Homogeneous vehicles, Single depot, Single product, Symmetric distance, Static environment, Deterministic demand and Time constraint. SSSSSD: single vehicle, single depot, single product, symmetric distance and static environment, Deterministic demand. SSMSSS: Single vehicle, Single depot, Multiple product, Symmetric distance, Static environment and stochastic demand. HESSSSD: heterogeneous fleet of vehicles, single depot, single product, symmetric distance and static environment, Deterministic demand. HSSSDS: Homogeneous vehicles, Single depot, Single product, Symmetric distance, Dynamic environment and Stochastic demand. HMSSSD: Homogeneous vehicles, Multiple depot, Single product, Symmetric distance, Static environment and Deterministic demand.
Problems with pickup and delivery starting by pickup load (PPDSP)	HSSSSDT: Homogeneous vehicles, Single depot, Single product, Symmetric distance, Static environment, Deterministic demand and Time constraint. HESSSSDT: Heterogeneous vehicles, Single depot, Single product, Symmetric distance, Static environment, Deterministic demand and Time constraint. HSSSDS: Homogeneous vehicles, Single depot, Single product, Symmetric distance, Dynamic environment and Stochastic demand. HMMSDS: Homogeneous vehicles, Multiple depot, Multiple product, Symmetric distance and Dynamic environment, Stochastic demand. HSSSDST: Homogeneous vehicles, Single depot, Single product, Symmetric distance, Dynamic environment and Stochastic demand and Time constraint. HSMSSD: Homogeneous vehicles, Single depot, Multiple product, Symmetric distance, Static environment, Deterministic demand. SSSSSD: single vehicle, single depot, single product, symmetric distance, static environment and deterministic demand. HMSSSDT: Homogeneous vehicles, Multiple depot, Single product, Symmetric distance, Static environment, Deterministic demand and time constraint.

Figure 1. The percentage of each master class



We concluded from those figures that the problem with pickup and delivery starting by pickup load (PPDSP) and the problem with delivery-and-pickup made at the same stop (PDPSS) are the most problems studied in the literature. The problem with deliveries made before all pickups (PDBP) is less treated, while the class of problems with delivery and pickup occur in any sequence (PDPOS) is the least studied because of the difficulty of goods rearrangement in vehicles.

Comparison Between the Resolution Methods Used for Each Master Class

In this part, we compare between exact approaches, classical (simple) heuristics, and metaheuristic-and-hybridization methods for each master class as follow:

For the problems with deliveries made before all pickups (PDBP), as shown in figure 2, metaheuristic and hybridization are the most methods used for solving problems with delivery made before all pickup loads. Authors used different metaheuristics for solving this class of problems with 73% of papers studied, while just 15% of works involves simple heuristics and only 12% used exact methods.

For the problems with deliveries and pickups made at the same stop(PDPSS), as seen from Figure 2, metaheuristic and hybridization are more used for solving problems with delivery and pickup occur in any sequence than exact methods and simple heuristics. In fact, 80% of all approaches are different metaheuristic and hybridization methods, while simple heuristics represent 13% and exact methods just 7%.

As in the other master classes, metaheuristic and hybridization methods are the most proposed for solving problems which belong to the master class starting by pickup load (PPDSP) with 68%. While exact methods present 26%, and at the end simple heuristics present just 6% of all proposed approaches for this class of problems.

Due to the NP-hardness of the problem under consideration, metaheuristic and hybridization methods are the most used for solving it as seen from the Figure 2.

Comparison Between Variants of Each Master Class

Comparison Between Variants of the PDBP

For the master class that contains problems with deliveries made before all pickups, the variant that uses metaheuristic and hybridization methods for homogeneous fleet of vehicles, single depot, single product, symmetric distance and static environment and deterministic demand (HSSSSD) is the most variants studied with 68%. While the least one is the variant that uses metaheuristics and hybridization approaches for the heterogeneous fleet of vehicles, multiple depots, single product, symmetric distance and static environment (HEMSSSD) with just 5% out up of all works.

We can conclude that there are several works missing in this master class. For example, the study of the variant (HEMSSSD) with time constraint, the (HEMSSSD) also with time constraint, a variant that considers multiple products, etc.

Comparison Between Variants of the PDPAS

The subclass of metaheuristic and hybridization methods contain three variants. The two most studied variants are heterogeneous fleet, single depot, single product, symmetric distance, static environment and time constraint (HESSSSDT) and homogeneous fleet of vehicles, single depot, single product, symmetric distance and static environment (HSSSSD) with 40% for each one of them. As future works, there are many suggestions such as adding the constraint of dynamism to the environment, multiple products, time constraint with homogeneous fleet of vehicles, etc.

Comparison Between Variants of the PDPSS

The subclass (metaheuristic and hybridization methods) contains many variants which belong to the master class (problems with deliveries and pickups made at the same stop). We conclude from this study that the variant which uses metaheuristic and hybridization for homogeneous fleet of vehicles, single depot, single product, symmetric distance and static environment (HSSSSD) is the most treated with 50%. While the variant that uses metaheuristic and hybridization for homogeneous fleet, single depot, single product, symmetric distance, static environment and time constraint (HSSSSDT) presents just 25% out of all works belong to this subclass. Variants that treat heterogeneous fleet of vehicles, single vehicle, multiple products, multiple depots or dynamic environment are the least considered in this master class between 4% and 9% for each variant.

Comparison Between Variants of the PPDSP

Researchers have proposed different metaheuristics and hybridization methods for solving problems with pickup and delivery of goods which start by pickup loads (PPDSP). The proposed metaheuristics are based on either local search, population-based search or learning mechanisms. The variant that uses homogeneous fleet of vehicles, single depot, single product, symmetric distance, static environment (deterministic demand), and time constraint (HSSSSDT) is the most studied in this class of problems with 33% out of eight variants. While variants that use for examples, single vehicle (SSSSSD), heterogeneous fleet (HESSSSDT), or dynamic environment with stochastic demand-and-multiple products (HMMSDS) are the least treated with just 5% for each variant.

Contributions With Stochastic Demand

Different methods are proposed to solve each problem with its specific features. Authors presented and developed many approximate and exact approaches for solving them. The works that have studied the vehicle routing problem with pickup and delivery of goods in case of stochastic demand is given: see Table 7.

As seen from this table, only 10 articles out up of 101 treated in our work have studied the VRPCD in case of stochastic demand. Almost 90% of the articles dealt with this problem in case of deterministic demand.

Summary of the Problems Classification

In this part, we gave a summary for all problems belong to the general problem of pickup and delivery of goods. The contribution of each class, each subclass and each variant is given as percentages (Figure 2).

Based on the work of James Allen (1984) in artificial intelligence that formalized the 13 topological relationships between time intervals, we modeled the classification of collection and delivery problems of goods according to the time of completion of the operation as follows:

Let:

The vehicle routing problem with delivery and pickup of goods can be defined by a complete graph $G = (N_0, E)$, where $N_0 = \left\{0, \ldots, n, n+1\right\}$, and the depot is represented by the node 0 and $n+1$. E is the set of arcs $\left\{i, j\right\}$, where $\left\{i, j\right\} \in N_0, i \neq j$.

Table 7. Contributions with stochastic demand

Method	Master Class	Features	Variant	Authors
Improved genetic algorithm	problems with pickup and delivery made at the same stop (PDPSS)	homogeneous fleet of vehicles/ single depot /single product/symmetric distance/dynamic environment/ stochastic demand	HSSSDS	(Hou and Zhou, 2010)
Double-horizon based heuristics (cheapest insertion procedure and tabu search)	problems with pickup and delivery starting by pickup load (PPDSP)	homogeneous fleet of vehicles/ single depot /single product/symmetric distance/dynamic environment/ stochastic demand/ time constraint	HSSSDST	(Mitrović-Minić et al., 2004)
Local search	problems with pickup and delivery starting by pickup load (PPDSP)	homogeneous fleet of vehicles/ single depot /single product/symmetric distance/dynamic environment/ stochastic demand/ time constraint	HSSSDST	(Fabri and Recht, 2006
A fix-and optimize heuristic and a genetic algorithm	problems with pickup and delivery starting by pickup load (PPDSP)	homogeneous fleet of vehicles/ multiple depots / multiple products/ symmetric distance/dynamic environment/ stochastic demand	HMMSDS	(Rieck et al., 2014)
Neighborhood search heuristics	problems with pickup and delivery starting by pickup load (PPDSP)	homogeneous fleet of vehicles/ single depot /single product/symmetric distance/dynamic environment/ stochastic demand	HSSSDS	(Gendreau et al., 2006)
An adaptive predictive control based on Particle Swarm Optimization (PSO)	problems with pickup and delivery starting by pickup load (PPDSP)	homogeneous fleet of vehicles/ single depot /single product/symmetric distance/dynamic environment/ stochastic demand	HSSSDS	(Cortés et al., 2009a)

continued on following page

Table 7. Continued

Method	Master Class	Features	Variant	Authors
Dynamic programming algorithm	2 classes: problems with pickup and delivery made at the same stop (PDPSS)/problems with delivery and pickup occur in any sequence (PDPAS)	single vehicle/ single depot /single product/symmetric distance/static environment/ stochastic demand	SSSSSD	(Minis and Tatarakis, 2011)
A scenario-based solution methododlogy	problems with pickup and delivery starting by pickup load (PPDSP)	homogeneous vehicles/ multiple depot /single product/symmetric distance/static environment/ stochastic demand/ time constraint	HMSSSDT	(Ghilas et al., 2016)
A new robust mixed integer linear programming (MIP) model	problems with pickup and delivery starting by pickup load (PPDSP)	homogeneous fleet of vehicles/ single depot /single product/symmetric distance/static environment/ stochastic demand/ time constraint	HSSSSDT	(Tajik et al., 2014)
Dynamic programming algorithms	problems with pickup and delivery made at the same stop (PDPSS)	single vehicle/ single depot / multiple products/ symmetric distance/static environment/ stochastic demand	SSMSSS	(Dimitrakos and Kyriakidis, 2015)

$N = \{1, \ldots, n\}$: the set of customers (pickup and delivery customers), $N = D \cup B$,

$N_0 = \{0, 1, \ldots, n, n+1\}$: the set of customers including start and end depot node, each vertex $i \in N$ represents a customer having a demand q_i

D: subsets of delivery (Linehaul) customers,

B: subsets of pickup (Backhaul) customers,

$$D := \bigcup_{i \in N} D_i$$

$$B := \bigcup_{i \in N} B_i$$

Figure 2. Summary of the problems classification

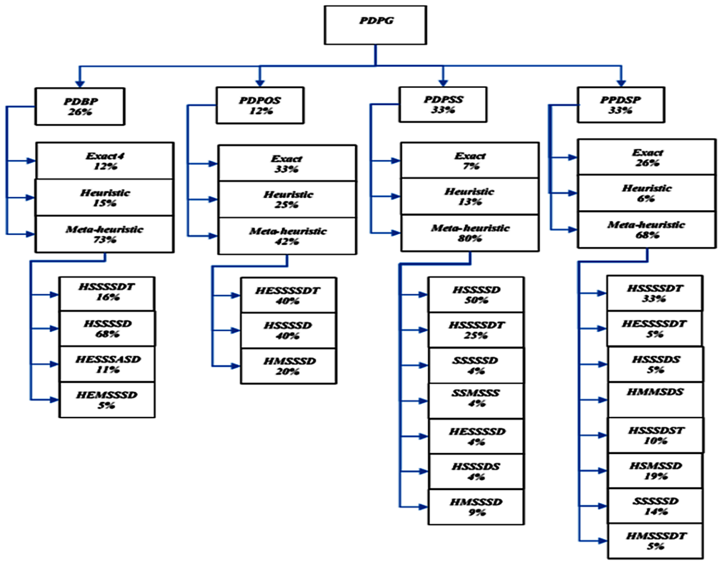
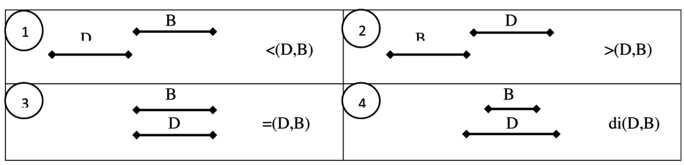


Table 8. Classification modeling



1 < (D, B): D before B; all deliveries customers are served before the pickups.

2 > (D, B): D after B; starting pickup load: exchange of goods between customers.

3 = (D, B): D equals B; delivery and pickup made at the same time (stop).

4 di (D, B): B during D; starting by delivering goods but pickup can occur in any sequence.

CONCLUSION

The Vehicle Routing Problem with pickup and delivery of goods (VRPCD) lies at the heart of the vehicle routing problem, and consequently at the distribution management. During the last decade, this stream of research drowns a growing interest of research community. A wide variety of exact and approximate algorithms have been used for the different variants of this problem. According to our framework of analysis, we have proposed a classification. This survey provided statistics on characteristics, methods of resolution and variants treated in the literature. Several promising avenues of research deserve more attention, such as stochastic demand, dynamic environment, time-constraint, multi-commodities. Based on this detailed study, one can know all the details of variants of the vehicle routing problem with pickup and delivery of goods. We can conclude, which variant is studied more than the others and what the gape is in the research. This work provides the direction for future research according to each master class, each method of resolution, and each variant.

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Chapter 3
Hierarchical Planning Models for Public Healthcare Supply Chains

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ABSTRACT

This chapter focuses on the hierarchical planning and execution for supply chain management in public healthcare services. The authors first introduce tiered organizational and services delivery structure of public healthcare services followed by various supply chain issues that public healthcare services encounters. They then review hierarchical planning and execution discussions for the strategic, tactical, and operational decisions in supply chain literature. They continue the discussion with public healthcare services cases on medicine and equipment maintenance supply chains. They compare hierarchical planning execution discussions in supply chain management literature vis-a-vis healthcare services cases. Their main argument is that much can be gained by the public healthcare services by striving for reduced information asymmetry and employing appropriate functional aggregation at various levels of the hierarchically organized public healthcare supply chains.

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PUBLIC HEALTHCARE SERVICES

Health is an indicator of an individual's quality of life, and access to healthcare services is one of the fundamental rights of human beings (WHO, 2017). With the advancement in technology, healthcare services have become quite specialized and the cost of healthcare has increased to unaffordable levels. The provision of quality and sustainable healthcare services is a huge challenge for organizations and governments, especially in the developing countries. Public healthcare comprises of complex chain of community workforce, with primary, secondary and tertiary level healthcare facilities to provide preventive, curative and specialized healthcare service delivery (Min, 2014). This service delivery chain or healthcare supply chain is supported by a network of government, semi-government and private organizations. The main objective of every healthcare system, particularly public healthcare system is the provision of best quality healthcare services to the patients at an affordable cost. To achieve this, healthcare organizations have to plan purposefully and to use their available resources efficiently while ensuring that healthcare services are accessible to all (Min, 2014). Public healthcare systems are organized in a tiered manner so that healthcare services reach across the population and that they are effectively managed.

Table 1. Types of Healthcare Services

	Examples of institutions	Examples of healthcare professionals
Primary care	Doctor's offices, clinics, schools, prisons, mobile vans	Family physicians, nurse practitioners, physician assistants, pediatricians, obstetricians, gynecologists
Secondary care	Community hospitals, specialty (e.g., cancer) clinics, diagnostic imaging labs, magnetic resonance imaging labs, intensive care units	Internists, cardiologists, oncologists, ophthalmologists, endocrinologists, dermatologists, geriatricians, orthodontists, neurosurgeons, orthopedic surgeons, psychiatrists
Tertiary care	Regional medical centers, medical schools, burn centers, birthing centers	Specialists, medical researchers, occupational therapists
Preventive care	Public health organizations, wellness and fitness centers, pharmacies	Chiropractors, fitness instructors, clinical dieticians, epidemiologists
Outpatient care	Nursing homes, assisted living facilities, outpatient surgical centers, rehabilitative centers	Hospices, care givers, nurses
Emergency (urgent) care	General hospitals, satellite clinics, ambulances, trauma centers	Paramedics, ER doctors

(Source: Min, 2014)

Community workforce, largely comprising of vaccinators and community mobilizers, are the first contact point, for healthy and unhealthy population alike, on basic healthcare issues (vaccination, safe delivery and pregnancy, etc.). However, in absence of robust community workforce, primary healthcare centers are typically first medical center for most people. Primary centers are generally provided with general practitioners. The aim of primary center is to provide easily accessible route to healthcare dealing with broad range of common illnesses, preventive care, physical and social problems, rather than specialists in any particular disease area (Center for Academic Primary Care, 2017).

Secondary healthcare centers serve as first referral point from primary centers. These centers have general practitioners and specialized consultants in some common areas of healthcare and basic level of diagnostic support. Health care services at this level include acute care, short period stay in hospital emergency or indoor department for brief but serious illness or trauma (Min, 2014). The third tier in this network, Tertiary healthcare centers, offer specialized consultative care, and are equipped with advanced diagnostic support services. Healthcare at tertiary level is provided usually on referral from primary and secondary health care centers. These different types of healthcare services combine together to form healthcare supply chain as shown in Table 1.

A hierarchical relationship exists between different tiers of public healthcare system in terms of the patient load and the level of healthcare facilities each tier offers. Primary healthcare facilities lie at the lowest end of the hierarchy followed by secondary and tertiary healthcare services. Quality of healthcare at these tiered service centers is ensured through a network of teaching institutes; drug and equipment manufacturers, retailers, and regulatory agencies; medical practices; regulating and monitoring bodies; international donors and technical partners; government health department and other organizations forming a complete healthcare supply chain.

These interlinked organizations in health system interact with each other within the context in which the health system is situated (Atun et al. 2006; Atun et al. 2007), thereby forming a whole with properties beyond the component parts (Checkland, 1981). The overall responsiveness of the healthcare system depends on the coordination among different organizations and units. This ensures the provision of quality human resource, medicines and vaccinations, infrastructure, equipment and supplies, medical standards (SOPs, SMPs) and other inputs necessary for quality healthcare service. Figure 1 depicts a stylized healthcare network that can be observed in most public healthcare systems.

Within limited resources, the sustainability of quality healthcare services is contingent upon the organizations' capacity to control and manage cost effectively. This requires the reevaluation of existing healthcare management policies and practices with the aim of reducing inefficiencies and achieving long-term productivity

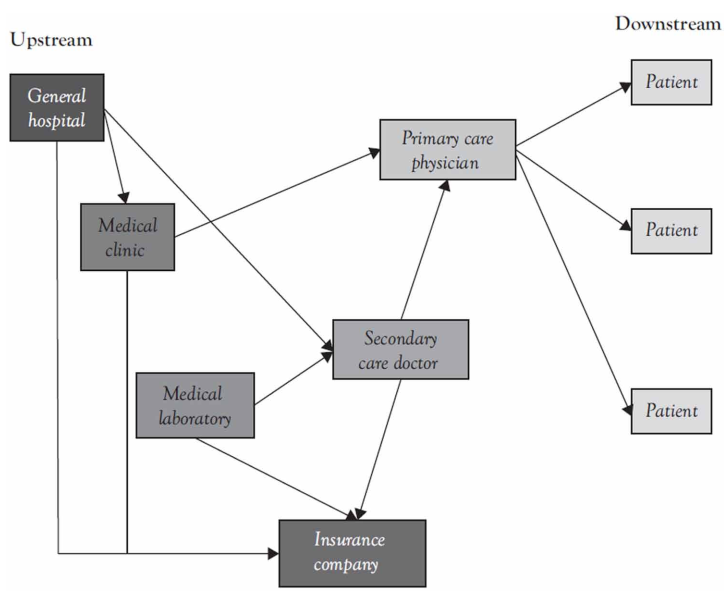
(Sanders, 2012). This chapter discusses supply chain management principles and hierarchical planning in the context of public healthcare systems. It evaluates hierarchical planning in healthcare organizations in the light of modern supply chain principles and illustrates how the integration of different processes, information and networks allow an organization to mitigate inefficiencies to achieve optimization.

HEALTHCARE SUPPLY CHAIN

What Is Supply Chain?

"A supply chain is the alignment of firms that bring products or services to market" (Lambert, Stock, and Ellram, 1999). Supply chain is also referred as an organization's ability to balance supply and demand so as to meet its end goal of satisfying customer needs (Gehmlich, 2008). A supply chain involves multiple steps, procedures and various stages like production, warehousing, logistics and distribution etc. The view that supply chains are limited to manufacturing sectors has evolved rapidly over the last decade. In the modern world, the importance of supply chain management has grown across different types of organizations –corporate, government, military and development agencies. Similarly, in the case of healthcare sector, with the

Figure 1. Network of healthcare supply chain
(Source: Min 2014)



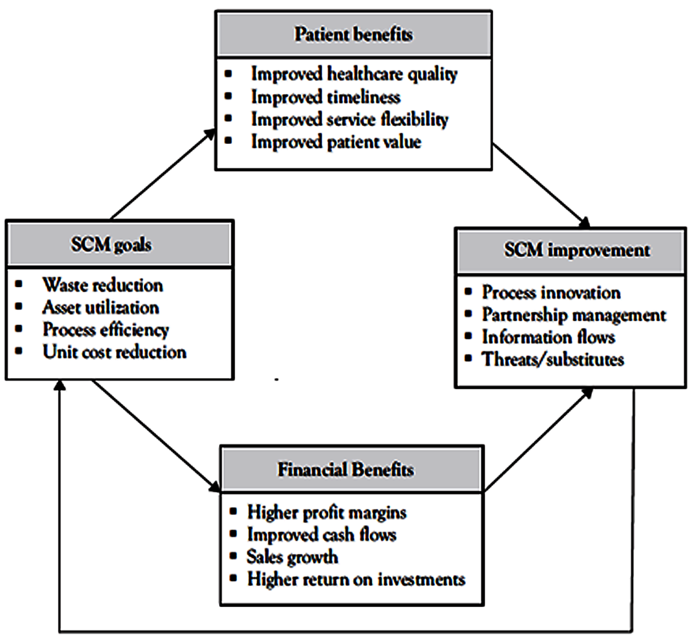
advancement of science and technology, healthcare has become quite specialized and supply chain management in healthcare systems has gained significance.

Healthcare sector in the modern world involves multiple stakeholders e.g. hospitals, medical practitioners, insurance companies, pharmaceuticals, and government regulators (Gehmlich, 2008). In order to manage specialized healthcare and to satisfy the patient needs, efficient supply chain management has become indispensable to the success of healthcare organizations (Gehmlich, 2008). Figure 2 depicts typical strategic goals and typical performance requirements of a typical healthcare supply chain.

Healthcare Supply Chain Management

Healthcare supply chain management is the supervision of resources by the healthcare service provider to the patient. It involves procuring goods and services, managing supplies and service delivery to the end user or patient. In this process of service delivery, multiple dependent and independent stakeholders are involved (Deloitte, 2013). The healthcare supply chain starts at the level of manufacturer where different healthcare related items like medicines, biomedical equipment and other supplies are manufactured. These items are either purchased directly by the hospitals, or

Figure 2. Strategic goals and performance measures of supply chain management (Source: Min, 2014).



in some cases, a procuring agency runs the procurement process on behalf of the hospitals. In either case, the procured items end up in the health facilities or the warehouses, where they are stocked and inventories are maintained. Healthcare supply chains are also driven by different legal frameworks administered by regulatory agencies. Public healthcare organizations consists of various attached units, vertical programs, local governments and regulatory agencies. These organizations along with pharmaceuticals, biomedical equipment manufacturers, insurance firms, suppliers and other entities are interconnected with each other, and make the healthcare supply chain as illustrated by Figure 3. Healthcare supply chain can be categorized into three main groups: producers, purchasers/ consumers, and providers of healthcare services (Mathew et al., 2013).

Producers

The producers in healthcare supply chain include pharmaceuticals that manufacture medicines, medical supplies and surgical equipment manufacturers, and firms that manufacture biomedical equipment. Since availability of quality medicines is essential for any healthcare system to function, pharmaceuticals are an integral component of healthcare supply chains. Similarly, functional and up to date equipment is necessary for timely and quality health care service provision. Thus, firms that manufacture biomedical equipment also play an important role as producers in the healthcare sector. With the advancement of research and development, biomedical equipment have become highly sophisticated and expensive. Pharmaceuticals and biomedical equipment firms are often connected to intermediaries that act as a channel of bringing the products to the markets. Local pharmacies and retailers supply medicines to the market. Similarly, hospitals often purchase medicines directly from the manufacturer or an intermediary. In some cases, where the quantity of medicines consumed is in high quantity, a procuring agency or group purchasing organization procures medicines and biomedical equipment on behalf of the hospitals. This is common in public healthcare systems where medicines and other supplies are consumed in huge quantities. In such a structure, centralized purchasing allows public healthcare organizations to benefit from price reductions as a result of bulk buying that leads to economies of scales.

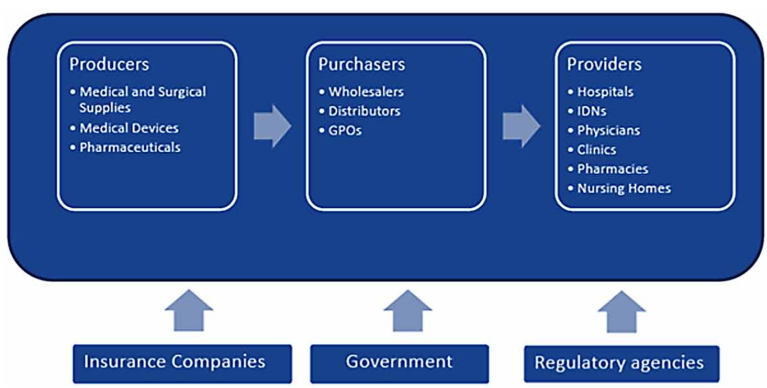
Purchasers

Intermediaries like wholesalers, distributors and group purchasing organizations, are classified as purchasers or consumers in the healthcare supply chain (Mathew, 1998). One of the largest purchasers in the healthcare industry is the government. In order to provide healthcare services to the masses, governments are the biggest purchasers of medicines as well as the biomedical equipment. Since governments have large demands, they often receive the supplies, especially medicines directly from the manufacturer. In other cases, depending on the nature of the product, it can also be delivered to the purchasers through a distributor. Healthcare supply chains are often described as disconnected and efficient. One of the main problems with the traditional healthcare supply chains is that each unit operates independently without effective coordination with the other units. This prevents the healthcare supply chain to work efficiently as an integrated system.

Providers

The providers of healthcare services include physicians, nurses, allied health professionals, dispensaries, clinics and hospitals. These healthcare professionals are related to each other e.g. the medicine prescribed by the physicians are dispensed by pharmacists. The providers of healthcare services are governed by regulatory agencies that keep check and balance on the activities of the healthcare staff and different units of the healthcare supply chain. Similarly, government regulatory agencies also check the quality if the healthcare service delivery in hospitals. As illustrated in the Figure 3, healthcare supply chain also includes insurance companies, government and regulatory agencies. The overall healthcare supply chain involves multiple stakeholders that work together to provide quality healthcare services. Consider for example the role of regulatory agencies; the drug regulatory authorities ensure that the medicines are manufactured as per the required standards and test the efficacies of medicines to ensure a high standard of medicines fit for consumption.

Figure 3. A typical healthcare supply chain
(Source: Mathew, et al., 1998)



Coordination in Healthcare Supply Chains

Since supply chains involve a network of different departments and units, effective coordination is essential to its success. Supply chains are dynamic and require effective flow of information about product, demand, supply and consumption etc. (Chopra, 2015). Customers are the most important part of the supply chain because the end goal of every supply chain is to meet the customer needs in the most effective manner. While the services or the products flow from the manufacturers to the customers, the flow of information is both ways i.e. information must be shared at each stage of the supply chain for effective coordination.

With technological advancement and globalization, businesses have become more specialized and markets have become more dynamic. Companies in the modern world have become flexible and have adapted to the changing requirements of the customers and growing markets. They effectively coordinate and partner with each other to avail each other's specialized services (Hugos, 2006). Traditionally, companies used to manage majority of the operations and services themselves, but this trend has changed rapidly over the last decade. For example, companies that had large inventories and supplies used to maintain warehouses on their own and arranged their own logistics, however, those companies are now seeking to outsource the services to specialized logistics management firms (Hübner, 2008). This allows the organizations to focus on their specialized core competency and also achieve operational efficiency.

HIERARCHICAL PLANNING IN ORGANIZATIONS

One of the classical ways of managing complex processes involving multiple decision is to 'divide and conquer'. This principle describes how an organization's complex planning tasks can be decomposed into smaller units. Each smaller unit serves as a 'decision unit' within the overall hierarchy of the organization (Stadtler, 2012). In a supply chain, where multiple departments and stakeholders work together, like in healthcare systems, planning and decision making is often based on a hierarchical planning system (Stadtler, 2012). Hierarchical planning in the context of supply chain management is essentially entails management decisions taken at different levels of the organization (Liberatore, 1985). Hierarchical planning divides the complex operations and planning tasks of an organization into smaller units or levels. These smaller units serve as decision points for higher level management, dividing overall complex decision problem into solvable levels.

Strategic, Tactical, and Operational Decisions in Supply Chains

In a typical supply chain, there are three types of decisions i.e. strategic, tactical and operational (see Table 2). These decisions are also based on a hierarchical levels, depending on their significance, timeframe and impact on the organization management. Strategic decisions are related to matters of strategic significance for the organization. These include main aims and objectives, main resources to be employed for production, warehousing capacity and broader marketing strategies. Strategic decisions are long term decisions and influence the overall organization. They are taken by the higher level management of the organization and are updated between 2-5 years. In a healthcare supply chain, strategic decisions relate to the total number of healthcare facilities, cost of healthcare etc.

Tactical decisions are those decisions that help an organization in achieving its main objectives. These decisions are medium term and are decided by higher and the mid-level managers. These decisions pertain to the available resources and whether they are sufficient enough to meet the main objectives of the organizations. Decisions relating to the procurement of medicines, biomedical equipment, management of inventories in warehouses and their distribution plans, for example, are characterized as tactical decision in healthcare supply chains. The tactical decisions are put into action by defining a short term framework that includes short term operational decisions. These operational decisions are day to day decisions like managing human resource, production procedures etc. Essentially, strategic decisions provides the basic framework for the tactical decisions while tactical decisions settle the framework for operational decisions. These decisions have a hierarchical relationship with respect to scope, time frame and nature of the decision.

Table 2. Strategic, tactical and operational decisions in a supply chain

Stages of Firms Activities	Respective Decisions at these Levels	Time Frame of Decisions
Strategic level	Decisions pertaining to network design and flow of materials through this network; the number, location and capacity of manufacturing and/or warehousing facilities.	2 to 10 years
Tactical level	Decisions include those relating to procurement, inventory, distribution, transportation and warehousing.	4 months to 12 months
Operational level	Decisions relating to manpower scheduling, product lead times, routing, loading and unloading, order acceptance and job acceptance rules	7 to 28 days

Hierarchical Structures for Organizational Management

The hierarchical planning is essential to the modern supply chain management. The hierarchical planning in an organization works like a system, where one component is connected to the other and the overall system. Decomposition of an organization into smaller units is a necessity for effective management. We provide the brief description of each of the smaller unit in Table 3. The decision unit at the top of the hierarchy usually takes decision of high significance in terms of organizational supply chain profitability and competitiveness. Such decisions have long term profitability impact and are taken by the top management or the policy and strategic planning unit of the organization.

The next level, usually termed as mid-level management follows the policy guidelines provided by the top level management and translate these policy guidelines to configure and decide on the tactical decisions. Examples of these tactical decisions include procurement strategy, inventory policies and third party contracting for transportation and warehousing etc. Typically, mid-level management is also responsible to collect necessary performance indicator data that allows higher management to deduce organizational performance in terms of competitiveness and profitability.

Next component in the overall hierarchy is the operational level management that is entrusted with day to day organizational management such as production and manpower scheduling, executing procurement purchase orders, distribution plans and reporting relevant key performance indicator data to the mid-level management. Each individual component in this system influences the other with positive or negative feedback, collectively determining the system's behavior (Senge, 1990).

Table 3. Organizational tiers of governance

High Level Supply Chain Planning and Management	Mid-Level Supply Chain Planning and Management	Low Level Supply Chain Planning and Management
Decisions pertaining to organizational supply chain design and planning that shall have long term impact on the profitability and competitiveness of the firm.	Tactical decisions those have midterm impact include those relating to procurement strategy, inventory policies, distribution plans, transportation and warehousing contracting and etc.	Decisions that are required for day to day functioning of the supply chain. For example, manpower and production scheduling, vehicle routing, loading and unloading, purchase order issuance and acceptance.

Hierarchical Planning Matrix for Supply Chain Management

When a decomposed supply chain of an organization is viewed with hierarchical planning structure, a hierarchical supply chain planning matrix is formed. Table 4 shows how different strategic, tactical and operational planning and execution tasks in a supply chain are arranged in a hierarchical structure.

Strategic decisions are taken at the top level of the hierarchical planning structure. These decisions are high level decisions that are usually non-recurrent and long-term in nature. Often these decision set the overall supply chain objectives and frameworks for the rest of the organization to follow. This include supply chain network design and other long term decisions that have greatest impact on organizational profitability and competitiveness (Stadtler and Fleischmann, 2012).

Decisions taken at the mid-level of the hierarchy are tactical decisions that set the midterm framework of the organization. In additional to these tactical decisions, the mid-level management supports the higher level management by providing necessary information that is used to establish benchmarks for organizational competitiveness and profitability. Guided by the mid-level management, short term or operational decisions are taken by the low level management. These decisions are operational in nature and are related to issues that occur almost daily (Stadtler and Fleischmann, 2012). Examples of such decisions include day to day production scheduling, service provisions, inventory ordering and transportation decisions.

Table 4. Hierarchical planning matrix for supply chain management

		Tier of Governance		
		Top Level	Mid-Level	Low Level
Type of Decision	Strategic	• Set aims & objectives of the organization. • Set the overall framework for supply chain. • Supply chain design decision. • Set key performance for profitability and competitiveness.	• Provides information inputs to assess profitability and competiveness.	
	Tactical	• Guide mid-level management for information requirements for strategic performance indicators. • Guide mid-level management to translate strategic aims into tactical requirements.	• Make operational policies to achieve objectives. • Devise procurement strategy, inventory policies, and distribution policies. • Engage third party contractors.	• Provides information inputs to assess tactical performance.
	Operational		• Provide guidance and oversight to low-level regarding implantation of tactical policies. • Guide low-level management for information requirements for operational performance indicators.	• Implements resource planning for day to day operations. • Executes production planning and service provision.

Information and Coordination in Hierarchical Supply Chain Planning Structures

In hierarchical planning structure of an organization, coordination and integration of different planning units is necessary. For effective and quality service delivery, it is important that all the stakeholders integrate effectively, and that the hierarchical planning is based on the effective communication and information sharing (Min, 2014). A hierarchical system of planning that is well integrated benefits the individual units and the organization as a whole. A well-integrated hierarchical system has effective coordination that helps in controlling the production and distribution costs of the products or the services. Such a system links decision making and communication, enabling higher level management to plan purposefully and take informed decisions.

When different decision units in the organization do not have the same level of information, lack of coordination is common that often lead to inefficiencies in supply chains (Schneeweiss, C. 2003). Schneeweiss used the term 'asymmetric information' to describe this situation. When different units are not well integrated with each other, the overall management of the system or the organization gets affected. One of the basic challenges that modern supply chains face is in achieving coordination in the presence of multiple stakeholders and units (Sunil Chopra, 2015). This lack of coordination in the supply chains often results in distortion of planning information leading to supply chain wide inefficiencies.

For effective coordination it is quite important for each stakeholder in the organization to recognize the significance of information sharing and its influence on the organizational efficiency in the first place. For example, sharing of customers/patients demand data across the healthcare supply chain is essential for effective resource planning. Similarly, medicine demand forecasting and procurement planning is performed by the mid-level managers. Sharing of accurate and timely medicine consumption data by the low level managers is essential for accurate medicine demand forecasting and consequent procurement planning.

Aggregation in Hierarchical Supply Chain Planning Structures

Another principle of hierarchical planning in complex supply chains is aggregation. It implies that within an organization, units that have similar functions and are directly related to each other should form an aggregate unit (Stadtler and Fleischmann, 2012). When units having similar interconnected functions form an aggregate, the coordination improves and supply chain wide inefficiencies can be reduced.

Consider the example of medicine procurement. One way to procure medicine needs is that each hospital or facility should directly procure medicines from the suppliers. Although each facility shall be in direct contact with the suppliers but this results in significant duplication of procurement efforts throughout the healthcare network. Alternative is to collect and consolidate the medicine demand and centrally procure the medicine needs for the entire healthcare network. This results in greater medicine procurement specialization, consolidating benefits and lower number of procurement transactions.

CASE STUDIES FROM PUBLIC HEALTHCARE

We now discuss the cases of medicine and equipment maintenance supply chains in the context of public healthcare. Healthcare services in Pakistan are provided by both public and private sector entities. The private healthcare sector comprised roughly 78% of all outpatient visits whereas 22% of the outpatient population was served by the public sector (Federal Bureau of Statistics, Government of Pakistan, 2015). The federal legislature passed the 18^{th} Amendment in July 2010, which stipulated provincial autonomy and devolution of legislative and executive authority for public healthcare services (Association of Primary Health Care Professionals for Pakistan, 2018).

Primary and Secondary healthcare department (P&SHD) is the main department assigned with the responsibility of healthcare development and provision in the province of Punjab, Pakistan. P&SHD operates around 2,950 medical facilities (hospitals and basic health clinics) at its primary and secondary healthcare levels throughout the province of Punjab to meet its goals of healthcare development and provision. In the forthcoming sections, we discuss the cases of medicine supply chain and equipment maintenance supply chain to highlight the applications of hierarchical planning principles in the context of public healthcare.

Our distinct advantage in studying these cases lies in first-hand access to experts and organizational data. The case study method was employed in assessing the state of medicine and equipment maintenance supply chain planning and execution within P&SHD. The research objectives of our study are exploratory and explanatory in nature where we aim to observe the state of hierarchical planning and execution of medicine and equipment maintenance supply chains at P&SHD. For this purposes, we mainly rely on primary data that is collected from interviews with key officials, archival search, P&SHD online sources and current internal documents. Wherever possible, we utilize publically available P&SHD sources to facilitate its appropriate citations. Methodological primary was given to the archival data and current internal documents to ensure that biases of the interviewees did not impact the case studies.

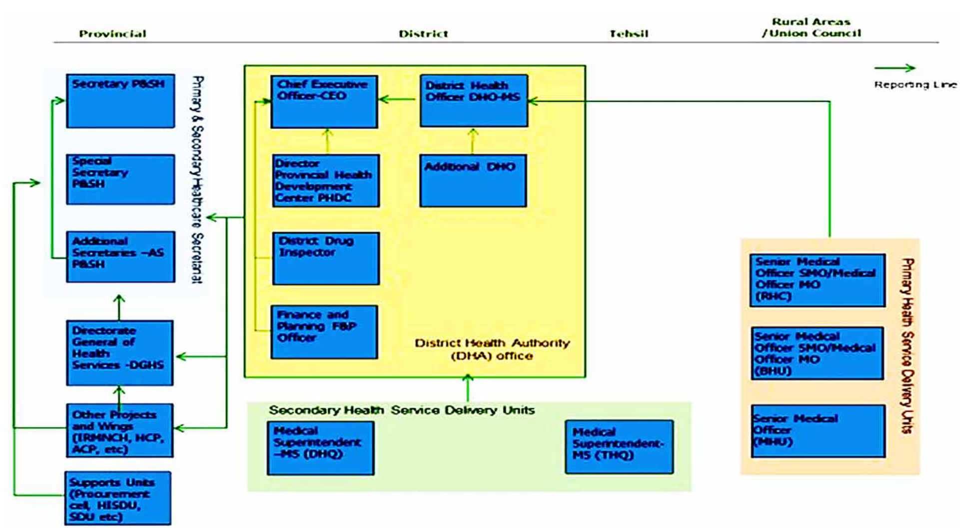
Primary and Secondary Healthcare Department (P&SHD), Punjab

In the province of Punjab, Primary and Secondary Healthcare Department (P&SHD) constitutes the main department assigned with the fundamental responsibility for healthcare development of the entire population of the largest populated province of Pakistan. P&SHD delivers on several levels; rehabilitative, promotive, preventive as well as curative healthcare services of primary healthcare level to secondary healthcare level

The organizational structure of the P&SHD shown in Figure 4 depicts the chain of command at both provincial and district level. The P&SHD is led by a Secretary, responsible for managing primary and secondary health provision in the province and for providing supervision, oversight and guidance of the entire constituent workforce. He is responsible to the Minister P&SHD and through him to the Chief Minister and the provincial legislature. The Secretary is assisted by a team comprising senior civil servants and public health specialists including a Special Secretary P&SHD, the Director General Health Services (DGHS), and five Additional Secretaries (AS) – one each for Administration, Drug Control, Vertical Programs, Development & Finance, and Technical wings.

The P&SHD's primary and secondary healthcare facilities, i.e., the first two tiers of service delivery, were under the supervision and control of district governments. The Chief Executive Officer (CEO) at the District Health Authority (DHA) was assisted by the District Health Official (DHO), Additional District Health Official

Figure 4. The organogram of the P&SHD



(ADHO), and Medical Superintendents (MSs) of various Tehsil and District Headquarter hospitals (Figure 4).

As mentioned, the P&SHD is responsible for the delivery of primary and secondary healthcare services in Punjab. We look at the two tiers; primary and secondary healthcare in more detail in the subsequent sections.

Primary Healthcare

At primary healthcare level, basic preventive, outpatient, and basic inpatient healthcare services are provided to three types of facilities; Basic Health Units (BHUs), Rural Health Centers (RHCs), and Mobile Health Units (MHUs). A list of eighteen (18) essential medicines is maintained at the primary healthcare level. These facilities are administratively managed by either a Medical Officer (MO) or a Senior Medical Officer (SMO). The MO/SMO is then responsible to the district head-CEO (Chief Executive Officer) at the District Health Authority (DHA).

The hospital bed size for a BHU and RHC facility at the union council level is that of 2-6 and 10-20 inpatient beds respectively. BHU serves a catchment population of up to 25,000 people while an RHC caters to a catchment population of 100,000 people. Services at BHU and RHC are similar and include basic promotive, preventive and curative services (P&SHD, 2016). MHUs are mobile units introduced to cater to remote rural populations at the tehsil level (Introduction of Mobile Health Units Tehsil Level, 2016). At present, there are a total of fourteen (14) MHUs currently operational in six districts, namely Muzaffargarh, Rajanpur, Mianwali, Dera Gazi Khan, Bahawalpur and Bahawalnagar.

Secondary Healthcare

Secondary healthcare facilities of THQ and DHQ cater to 0.5 to 1.0 million and 1 to 3 million respectively. THQ and DHQ hospitals cater to populations of 0.5 to 1.0 million and 1 to 3 million respectively. The bed size at the THQ and DHQ facilities varies between 40 to 60 beds and from 80 to 600 beds respectively.

THQ serves a tehsil which is a tier of local government. Several tehsils join together to form a district which in turn collectively form a province. A total of 145 tehsils and 36 districts make up the province of Punjab. Secondary healthcare provides specific technical, therapeutic, or diagnostic services covering outpatient, inpatient, and specialist care (P&SHD, 2016). Secondary healthcare facilities maintain a list of 100 essential medicines and are administered by Medical Superintendents (MS).

MEDICINE ACQUISITION AND DELIVERY IN P&SHD

Medicines are acquired centrally by P&SHD, according to the provisions of the Drugs Act 1976/DRAP Act, 2012/Punjab Drugs (Amendments) Act 2017 and rules framed thereunder. For the year 2017-18, a total of 218 medicine and supplies were centrally purchased by P&SHD. Majority of the medicine and supplies demand, pertaining to these 218 items is centrally procured through a framework contract.

The annualized acquisition of medicines makes use of an elaborate system of medicine data collection and procurement, with a centralized medicine delivery system employed to distribute inventories through the various storage/warehousing locations.

The medicine acquisition and delivery system is made up of three levels of hierarchy that vary in their duties and responsibilities in an organization. Daily, operational tasks are mostly carried out by the low-level of the hierarchy; facility level staff, support staff, researchers and analysts, ground level staff at provincial and district level. These operational tasks are supervised by the mid-level; district heads (CEOs, ADHOs, DHOs), facility heads (MSs and SMOs/MOs), warehousing and distribution managers, department specialists, support staff heads. The mid-level tier, in addition to various tactical duties ultimately report and assist the high level of governance in strategic decision making. The high-level consists of Secretary P&SHD, Special Secretary P&SHD, the Director General Health Services (DGHS), and five Additional Secretaries (AS) (see Table 5).

In the medicine supply chain, each level of hierarchy serves as a primary decision making body for specific functions of the organization. Although decisions pertaining to these functions are spread across multiple levels they are, however, depending on the function itself, concentrated at specific levels of an organization. Decisions pertaining to medicine network design and flow of medicine through the network are mostly concentrated in the high level. Majority of the decision-making in matters of procurement, inventory, distribution, transportation and warehousing is done at the mid-level of the hierarchy whereas the tasks of manpower scheduling, product lead times, vehicle routing, loading and unloading, purchase order issuance and acceptance are delegated to the low level of the hierarchy. Table 5 depicts functional decisions discussed and the corresponding hierarchical levels at which these functions are concentrated in medicine supply chain.

Medicine Acquisition: Demand Collection and Procurement

The collection of medicine demand from primary and secondary healthcare facilities takes place annually and forms the basis for the hierarchical planning of the centralized procurement of medicines

Table 5. Organizational tiers of governance for medicine supply chain

High Level Management	Mid-Level Management	Low Level Management
Decisions pertaining to medicine network design and flow of medicines through the network e.g. the number, location and capacity of manufacturing and/or warehousing facilities.	Decisions include those relating to medicine procurement, inventory, distribution, transportation and warehousing.	Decisions relating to manpower scheduling, medicine data collection, product lead times, vehicle routing, loading and unloading, purchase order issuance and acceptance

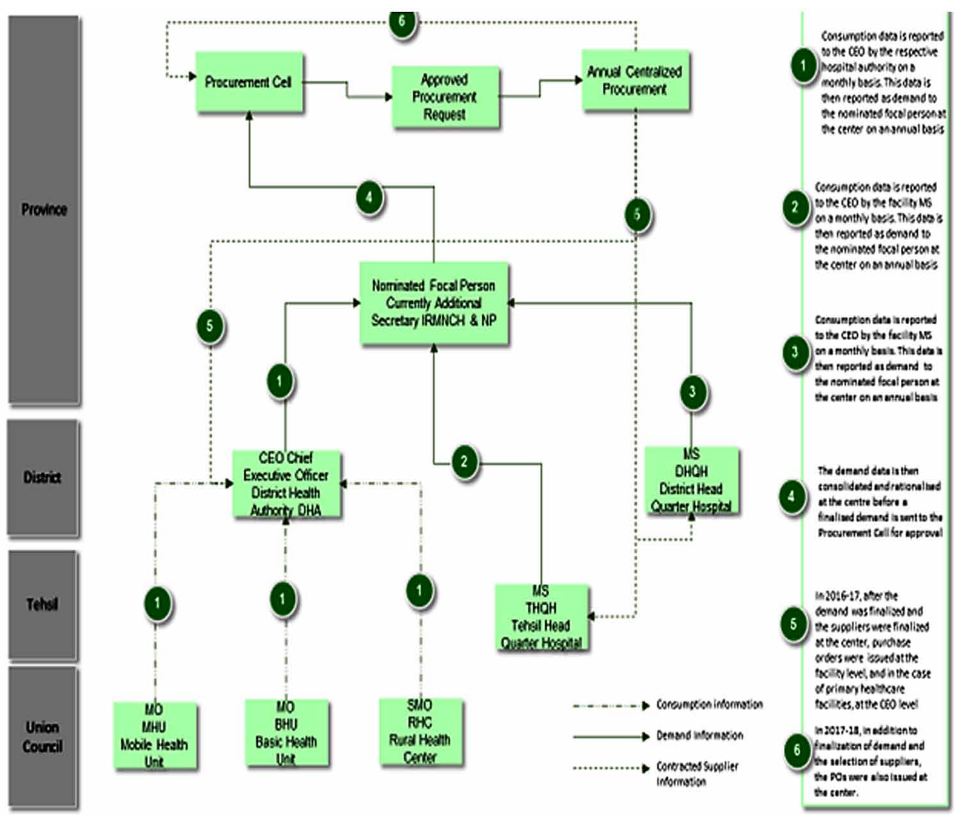
At the low level of the hierarchy, current medicine consumption data is collected on a daily basis at both primary and secondary facilities, by the hospital staff which in this system, form the smallest decision unit of the P&SH network (see Figure 5). In addition to collecting medicine data, this decision unit at the hospital is also responsible for carrying out other operational activities such as managing, recording and tracking inventories, and feeding relevant data into central databases and/or portals. The low level management supports mid-level management by providing them with summary reports, carrying out basic level analysis on these medicine consumption figures and documenting processes/procedures followed at facility and district level. The low-level management is also responsible for maintaining IT infrastructure required e.g. databases/dashboards and/or portals, to support the overall medicine demand collection framework.

The consumption figures are consolidated and rationalized at the tactical stage by the mid-level of CEOs for the primary healthcare level facilities, and the MSs for the secondary healthcare facilities (see Figure 5). Other tactical tasks performed by the mid-level include making their own summary reports and conducting advanced level analysis based off the information provided by the low-level staff. Department heads and support staff specialists are also involved with overlooking the development of all IT infrastructure used by the low-level staff for keying in medicine consumption figures. At the operational stage, mid-level employees undertake performance management of the low-level staff in addition to monitoring and evaluating whether operational medicine targets are met at district and facility level. At strategic stage, the mid-level ensures that the medicine figures are in line with the overall framework of medicine supply chain; this includes ensuring medicine KPIs are tracked, minimum stock level of items of a defined medicine list is maintained, and that the overall targets against the defined KPIs are on track and the procurement budget is followed.

The consolidated consumption figures are then reported as annual demand by the CEOs and MSs to a nominated authority at P&SHD who consolidates the figures and performs demand rationalization (see Figure 5). District budget, expert opinions, consumption rates, category of medicines, burden of disease, and departmental usage (indoor/outdoor/emergency usage) are all considered to reach a more realistic demand figure.

The high-level management also ensures that demand information forwarded form below is fed into an e-procurement software by three independent stakeholders, i.e., at the THQ and DHQ facilities, CEOs of each district who collect demand data through medical officers and senior medical officers of all the BHUs, RHCs and MHUs. Approving IT infrastructure such as an e-procurement to support the overall framework of the supply chain also comes under the tactical responsibilities of the high-level staff. Other tactical responsibilities include reviewing summary reports and advanced level analysis of the mid-level and conducting performance management of mid-level staff. At strategic level, defining the overall framework of medicine KPIs to use, minimum stock to maintain at facility level, medicine list to maintain, setting overall targets to achieve against the KPIs established, deciding between centralization vs decentralization of demand collection, establishing procurement budget are some of the duties of the high-level management.

Figure 5. Flow of medicine data from union council to provincial level



The rationalized demand figure is then forwarded to the department of Procurement Cell by the nominated authority at P&SHD which conducts the procurement bidding activity (see Figure 5). The low-level staff of the Cell conducts operational activity of generating purchase orders (POs) through the e-procurement software centrally, where a consolidated quantity at an agreed rate is specified to the selected supplier. The low-level staff is also involved in developing documentation and formulary for carrying out the procurement activity. The mid-level management of the Procurement Cell (i.e. Procurement Specialists) overlook the PO generation process and ensure that bidding methodologies, procurement criteria, and general procurement related protocols are being followed. They overlook and supervise the procurement infrastructure at a strategic level and carry out performance management of the low-level management by monitoring targets.

Some important procurement related decisions taken by the high-level management include centralization vs decentralization of procurement activity and centralization vs decentralization of PO generation. High level management also establish what bidding methodology and procurement criteria to follow, and decide on how much funds to allocate for the purchase of medicine. The flow of medicine data through the geographical hierarchy in Figure 5.

Medicine Delivery: Warehousing and Distribution

After the medicine is acquired, the medicine inventory makes it way throughout the health network through a centralized distribution system. The distribution process for the centrally purchased medicine is organized in a hierarchical manner, with deliveries made by the supplier, over a specified time period, directly to a central warehousing facility of Medical Store Depot. Medicine samples are sent to Drug Testing Labs (DTL) testing for the MSD, and medicine is only forwarded to the DHQ, THQ and CEO levels after their respective batches have been clearance (see Figure 6). The forward distribution is outsourced to third party service providers who distribute the medicine stock to the end-user facilities.

The high-level management at P&SHD is involved in strategic decisions of network design: number, capacity and locations of warehouses, hospital facilities and DTLs as well as the guiding coalitions to involve in the overall functioning of the system. Other decisions at this stage include deciding between centralization vs decentralization of drug testing and warehousing and choosing between an outsourced or in-house distribution strategy. The high-level management decides the frequency and protocols of drug testing, establishes production timelines with suppliers, develops distribution plans, and decides on delivery installments, vehicles and inbound/outbound rates to use.

At the MSD and other warehousing locations, the mid-level hierarchy of warehousing and distribution managers overlook the functioning MSDs and ensure that the overall distribution strategy is being followed. At this stage, they ensure that the protocols of drug testing and distribution activity and are being followed. They also assist the high-level management to establish and oversee that the distribution plans, delivery schedules and installments, vehicles and inbound/outbound rates are used and followed. The staff at the mid-level also document the processes/procedures followed at the warehousing locations and make summary reports and carry out advanced level analysis. The low level management at the MSD undertakes operational tasks of following forwarded distribution plans, delivery schedules and installments, vehicles and inbound/outbound rates. They also feed information in central inventory databases/dashboards and/or portals wherever such an infrastructure exists.

At district level, medicine stock is stored at storerooms at the CEO office to cover for the BHU/RHC/MHU demands, and directly at the respective facilities to meet the DHQ/THQ requirements. The support staff of the low level at facilities undertake the operational tasks of tracking inventory status and feeding information in central inventory databases/dashboards and/or portals. They also undertake tasks of documenting the processes/procedures followed at the facility locations and making summary reports and carry out basic level analysis.

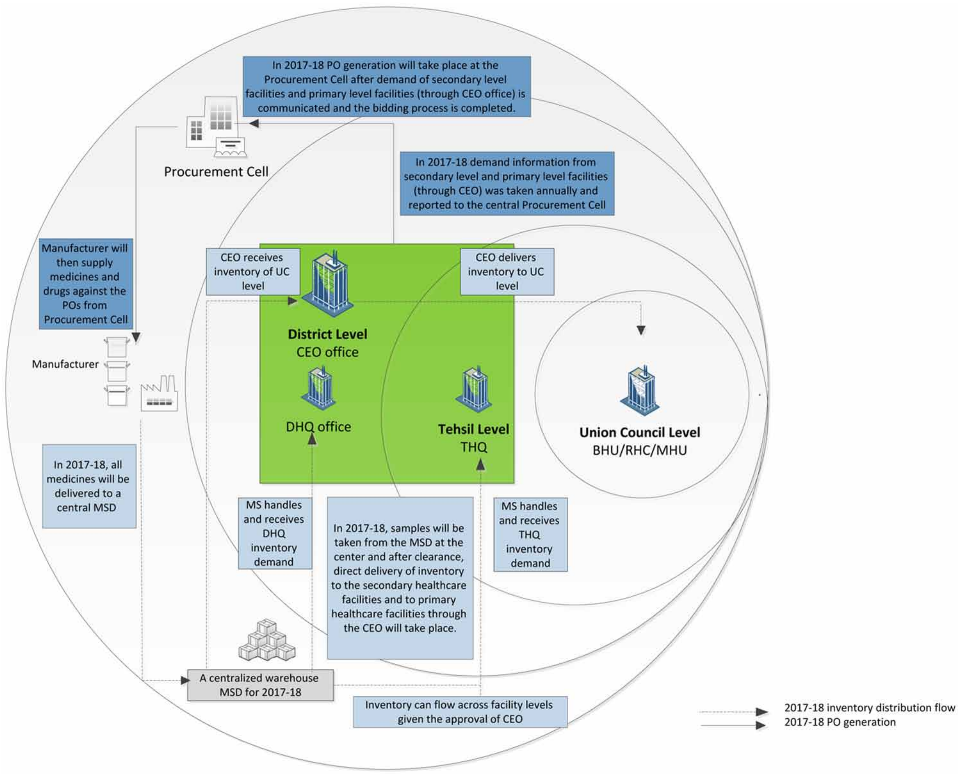
The warehousing network is hence organized in a tiered manner which, unlike the hierarchy in the procurement function, is spread geographically with inventory flowing in a top down manner from the center MSD to three levels— DHQ level and THQ level for secondary healthcare, and the CEO office level (DHA) which handles the union council-primary healthcare facility's inventories (BHU/RHC/MHU). The process of procurement, distribution, and sampling for the financial year 2017-18 is depicted in Figure 6.

The tier of governance based on the chain of command for the medicine supply chain, with focus on functions of medicine demand collection, procurement and warehousing and distribution is shown in Table 6

Information and Coordination in Medicine Supply Chain

As discussed, the hierarchical planning of acquisition and delivery of medicines is carried out in a centralized manner with various functional decisions relating to procurement and distribution spread across the different levels of the organization. With such a system in place, the requirement for coordination and integration assumes a greater importance to centrally manage and align said procurement and distribution decisions.

Figure 6. The process of procurement, distribution, and sampling for the 2017-18 financial year



The inputs for majority of the procurement related decision making at the high level comes from the databases maintained at the facility level. The flow of information hence follows a bottom to top approach. The databases maintained at ground level include centrally managed Prescription Management Information System (PMIS) and Equipment and Inventory Management System (MNE). Apart from maintaining these central databases, ground level staff also maintain medicine data in paper format for facility record keeping purposes. Information on facility wise data on medicine consumption in last month, along with medicine inventory balance is recorded through the Monitoring and Evaluation Assistant (MEA) application. The mid level management of the hierarchy makes use of the E-procurement system to input demand figures and generate POs, while the high level uses the same system to finalize and consolidate district and facility level demands.

In case of distribution, the information flow is from top to bottom as the PO and demand information is used by the high level to generate distribution plans that are eventually executed by the mid and low level staff. In addition to this, tactical

Table 6. Tiers of governance in medicine supply chain (based on chain of command)

Tier of Governance (Based on Chain of Command)			
	Top Level (Secretary P&SHD, Special Secretary P&SHD, DGHS, AS)	**Mid Level (District Heads (CEOs, ADHOs, DHOs), Facility Heads (MSs and SMOs/MOs), Warehousing and Distribution Managers, Department Specialists)**	**Low Level (Facility Level staff, Support staff, Researchers and Analysts, Ground level staff at provincial and district level)**
STRATEGIC LEVEL	● Set the overall framework of medicine supply chain o Which KPIs to use at central level; set overall targets to achieve against the KPIs established o Which medicine list to maintain at which healthcare level; What min stock level to maintain at the facility level ● Decide on number and capacity of warehouse, DTL, hospital and working space locations and guiding coalition involved ● Decide centralization vs decentralization of drug testing, medicine demand collection, procurement and warehousing ● Decide whether to outsource (and which 3PLs to engage) or develop distribution in-house ● Establish budget to spend on procurement activity	● Ensure that the overall framework is followed o Ensure KPIs are tracked; ensure that overall targets against KPIs is on track o Ensure medicine list is maintained; ensure min stock level is maintained ● Overlook the functioning of warehouses, DTLS, hospitals and working spaces ● Overlook the centralized or decentralized drug testing, medicine demand collection, procurement and warehousing infrastructure ● Overlooking the distribution network ● Follow budget to spend on procurement activity	-
TACTICAL LEVEL	● Set and approve the direction for policy frameworks for medicine supply chain components o Decide whether to decentralize PO generation o Establish frequency and protocols of drug testing, demand collection, procurement (bidding methodology and criteria) production timelines, and distribution activities at district and facility level o Decide chain of command senior-mid level officials o Consolidate demand and carry out demand rationalizations at provincial level o Establish distribution plans; decide on delivery installments, vehicles size and inbound/outbound rates ● Approval of resource allocation to the functioning of established framework (e.g. HR, logistics, internet data usage) ● Approve the setting up of all IT infrastructure required to support the overall framework e.g. databases/ dashboards, portals ● Monitor and oversee that frameworks are being followed and that installed systems are functional ● Performance management of mid-level staff ● Review summary reports and advanced analysis	● Assist the top level in generation of policy frameworks for medicine supply chain components o Overlook PO generation o Ensure the frequency and protocols of drug testing, demand collection, procurement (bidding methodology and criteria) production timelines, and distribution activities are followed at district and facility level o Decide chain of command and JDs of mid-lower level officials o Consolidate consumption data and carry out rationalizations at district level o Establish and oversee that distribution plans, delivery schedules and installments, vehicles size and inbound/outbound rates are followed o Make summary reports and carry out advanced analysis and document processes or procedures followed at district level ● Allocate and manage resources for the functioning of established framework (e.g. HR, logistics, internet data usage) ● Overlook the development of all IT infrastructure required to support the overall framework e.g. dashboards, portals	● Carry out activities to support policy frameworks for medicine supply chain components o Make summary reports and carry out basic level analysis o Document processes/procedures followed at facility and district level ● Manage and utilize resources for the functioning of established framework (e.g. HR, logistics, internet data usage) ● Develop IT infrastructure required to support the overall framework e.g. databases/dashboards, portals

continued on following page

Table 6. Continued

Tier of Governance (Based on Chain of Command)			
	Top Level (Secretary P&SHD, Special Secretary P&SHD, DGHS, AS)	**Mid Level (District Heads (CEOs, ADHOs, DHOs), Facility Heads (MSs and SMOs/MOs), Warehousing and Distribution Managers, Department Specialists)**	**Low Level (Facility Level staff, Support staff, Researchers and Analysts, Ground level staff at provincial and district level)**
OPERATIONAL LEVEL		• Set protocols for ensuring that frameworks are followed and installed systems are functional • Performance management of low-level staff • Monitor and evaluate the achievement of operational level targets at facility and district level	• Carry out operational level activities to meet targets at facility level o Carry out drug testing; generate POs o Develop documentation and formulary for procurement o Manage, collect, record and track all medicine related data at facility and district level, and feeding information in central databases/ dashboards, portals o Follow forwarded distribution plans, delivery schedules and installments, vehicles and inbound/ outbound rates

decisions regarding delivery installments, vehicles size and inbound/outbound rates are made in light of information on facility requirement and budget allocation by the high/mid-level of the management. The documentation of facility processes for both the procurement and distribution functions is done by the low level, with summary reports forwarded to the mid-level staff that in turn use the reports to document the operations at the district level. These reports are then used by the high level management in order to see an overall integrated picture of district and facility operations.

The decision making at the various levels as indicated is hence a value adding process, whereby the output of decision making unit is built upon and used as an input by another decision making unit. The current system can be improved through a complete harmonizing of inputs and outputs via properly integrating so as to avert any information asymmetry, through a mature IT system. The planning processes at various levels of the organization will then be implemented and executed effectively as internal information systems work with real-time, integrated data sets for driving outputs.

For example, for the centralized system of demand collection to be effective, there needs to be a mechanism through which the stakeholders at THQ/DHQ and CEO level can input their current consumption and/or expected demand figures. This system should also ideally have a central rationalization model built in, which based on the consumption and demand figures, allows for a more structured approach in the consolidation process. Lastly, POs should automatically be issued based on final consolidated demand calculated by the rationalization model. Such a system ensures that the outputs of one decision making unit, in this case, the low level management of THQs/DHQs and CEO, is directly used by the high level of management, in this case, the AS Vertical Programs, to input in the central rationalization model of the system.

Aggregation in Medicine Supply Chain

In terms of network hierarchy, the primary health facilities form part of a larger union council level, which combined with the secondary facilities are overseen by the district head of CEO. These district heads are in turn responsible to the authorities at the center of Secretariat P&SHD.

The aggregation of the procurement and distribution decision making in the medicine supply chain follows from this geographical spread of the hierarchy in the healthcare system. The strategic decisions, relating to network design and procurement amounts and methodologies, are taken at the center; by the Secretariat P&SHD. The decisions pertaining to resource allocation, infrastructural development, minimum stock maintenance, medicine list maintenance are done collectively at the top/mid-tier of governance for all the facilities in the network.

For central procurement of medicine and supplies, supplier selection and procurement bidding/purchase order issuance is also carried out at the center, on behalf of individual facilities and districts. The aggregation of procurement activity has allowed the center to track how much medicine has been centrally purchased and for which consumption points. The provincial authority can also use its leverage in case of delivery or quality issues from any supplier given such aggregation of procured quantities. Another benefit of aggregation comes from savings in terms of order transaction costs at various consumption units.

In case of distribution, the delivery of different medicine quantities and types at various facilities follow a centrally generated plan thereby releasing economies of scale in transportation. The warehousing of medicines is collectively done at a central MSD or district stores. In the case of this centralized delivery, the supplier can realize economies in production by producing and shipping larger batches of medicines to the centralized facility, the sampling of medicines is aggregated to realize significant reduction of samples for testing and a substantial decrease in the lead-time for drug testing.

Maintenance of Biomedical Equipment

Biomedical equipment, just like medicines, professionals and hospital infrastructure, forms a necessary part of the healthcare supply chain. In the context of a public healthcare network, several key stakeholders come together to provide for the masses, which demands for efficient coordination and integration between departments and individuals. Such a level of integration requires up to date flow of physical infrastructure, information and finances. Equipment and its maintenance is part of the physical flow in the healthcare supply chain and is of utmost importance for the integration and coordination that results in a successful healthcare service delivery chain.

Equipment Present at the P&SH Facilities

There are 97 types of regularly monitored essential biomedical equipment present at primary and secondary healthcare facilities, Punjab (Monitoring and Evaluation Assistants, 2015). There are two main types of equipment i.e. medical and non-medical equipment. Examples of medical equipment are ventilators, defibrillators, X-ray machines and nebulizers etc. Non-medical equipment includes ambulances, air-conditioners, furniture and other office supplies.

Equipment present at the primary and secondary healthcare facilities differ in number, nature and usability. Secondary facilities contain critical equipment that is needed for therapeutic and treatment purposes, while equipment at the primary level is mostly for diagnosis purposes. Criticality of the equipment is measured by the frequency of its use and its impact on patient's life in case of its non-functionality. Table 7 shows a list of critical equipment maintained by primary and secondary healthcare facilities.

Examples of equipment at primary healthcare facilities includes Blood Pressure apparatus, thermometers, syringes etc. in addition to the equipment present at the primary level, secondary healthcare facilities contain equipment such as X-ray machines, intensive care units, life support systems, ventilators, anesthesia machines etc. According to an internal audit conducted by the Monitoring and Evaluation Associates (2015), as of November 2015, total number of equipment present in 36 districts of Punjab was 15,725, out of which 14,045 was functional and 1,680 was non-functional.

Each DHQ has total biomedical equipment of worth PKR 200 million and each THQ has total biomedical equipment of worth PKR 100 million. Biomedical equipment is an essential part of the healthcare supply chain, as it ensures timely diagnosis and treatment of patients. In case of unavailability or malfunction of equipment, consequences to patient's health could range from delayed treatment resulting in complications to even death, depending on the nature and need of the equipment. Continued maintenance and availability of biomedical equipment is thus, important for efficient healthcare provision and patient safety. It was reported

Table 7. List of critical equipment

List of Critical Equipment:	
Sr. No.	Name
1	Anesthesia machine
2	Ventilators (All types)
3	Hemodialysis Unit
4	Defibrillator
5	Infant Incubators with Resuscitation system
6	Static X-Ray Machine
7	C-arm
8	Mobile X-ray
9	Dental X-ray
10	Ultrasound Machine
11	Colour Doppler
12	Chemistry Analyzers
13	Hematology Analyzer
14	Eye operating microscope
15	Lasers
16	Slit lamp
17	Auto ref
18	Endoscope
19	ETT machine
20	ELISA Machine
21	Phacoemulsification

that maintenance costs for DHQs can go up to PKR 5 million and are around PKR 1-1.5 million for THQs (P&SHD, 2016).

Organizational Structure for Equipment Maintenance

The healthcare supply chain for equipment management has a hierarchical organization that is divided at the central/top level, district/mid-level and facility/low-level. The Primary and Secondary Healthcare Department (P&SHD) secretariat compromising of the health secretary, special secretary, additional secretaries, deputy secretaries and section officers form the top-level management who take all the policy and strategic level decisions. Biomedical Equipment Resource Center (BERC) comprising of zonal heads, divisional engineers, and directors of medical workshops, procurement specialist and call center management makes up the tactical and operational arm for all equipment related concerns. BERC can be seen as the mid-level management in this case as decisions regarding execution, monitoring and management of central and regional resources is handled by it. The primary and secondary healthcare facilities that is the BHUs, RHCs, DHQs and THQs make up the low-level management which are mostly involved in the operational and execution related tasks. The facility management like the MS, admin officers, logistics officers and other relevant human resource (HR) liaison with the higher-level authorities and maintenance providers to carry out the day to day equipment management tasks. Table 8 highlights the functions and decisions taken at each level.

There are three medical workshops located in Lahore, Multan and Sargodha that cover the central, southern and northern zones of the province. The workshops started operations in 1985 and have been in use since then. These workshops were the only central resource available for equipment maintenance and are being refurbished to cater to the more complex maintenance queries. Moreover, 9 mobile workshops equipped with necessary tool kits and condemnation machines are used to assist these thee static workshops. At the central level, these Static and mobile workshops, internal engineers as well as a few pre-qualified third-party maintenance companies are managed under BERC to carry out the maintenance requests.

The computerized maintenance management system (CMMS), all the equipment data, call center operations, training and inspection and contract management in addition to the preventative and corrective maintenance is handled by BERC. Most of the information flow, physical flow and the financial flow takes place at BERC - the mid-level management. The resources available at this level are the call center, training center and vital information collection and dissemination. Information sharing is done in the shape of contact management, inspection and trainings. Physical flow is the availability and use of the physical infrastructure like the BERC center, tools, workshops and maintenance kits etc. The financial flow involves the expenses and budgeting.

At the facility level, resources such as the information about the local maintenance market and a well-established network are available to aid the equipment maintenance. Moreover, some facilities have in-house biomedical engineer or other technical assistance in addition to the HR that facilitates the maintenance and equipment management procedures.

Table 8. Organizational tiers of governance for equipment maintenance

Primary and Secondary Healthcare Secretariat - Top Level Management	BERC - Mid Level Management	Facilities - Low Level Management
Makes the policy framework and takes decisions regarding development, hiring and quantity of infrastructure, HR and other resources.	Sets the operational framework and maintenance systems.	Executes the policy and operational frameworks set by higher authorities.

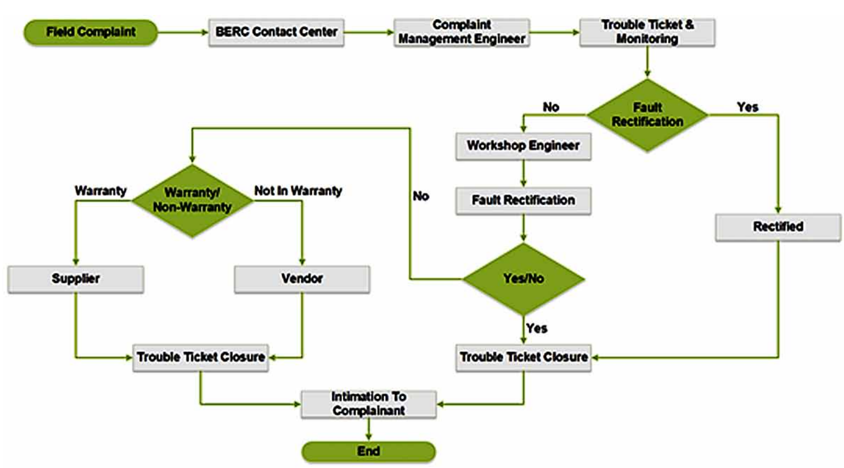
Equipment Maintenance Workflow

Equipment maintenance chain involves multiple stakeholders: health facilities, district authorities, P&SH secretariat, procurement cell, service providers, Original Equipment Manufacturers (OEMs), medical workshops and other relevant resources at all levels. Effective maintenance means that information and coordination between these stakeholders is ensured. BERC acts as a one stop shop for all equipment related queries, and a formal standard operating procedure (SOP) along with a centralized equipment maintenance regime. BERC ensures a smooth flow of information, resources and finances and acts as a tactical/executionary body that not only performs the maintenance process but also coordinates and updates all the stakeholders involved.

Figure 7 depicts how a typical maintenance request is handled by the centralized maintenance services structure (BERC) at primary and secondary healthcare department, Punjab. A complaint request is generated from the facility by the staff in charge after a fault is recognized and approved by the facility MS. The complaint management engineer (CME) at BERC receives the maintenance request in the form of a call and lodges a complaint ticket in the system. A complaint number is generated, after which the CME asks a few questions about the equipment and its status to check it against the equipment database comprising all the information regarding the tagged equipment.

If the equipment is under warranty or has an SLA agreement, the CME notifies the relevant company/service provider who is responsible for the maintenance

Figure 7. Equipment maintenance workflow



and reports back to the CME so the complaint ticket is closed and database is updated. If the equipment is not under warranty, depending on the status, history and information of the equipment, the CME checks if it is a minor default that can be fixed over the call. In case of successful repair, the complaint ticket is closed. If however, the complaint needs physical inspection and greater expertise, the CME calls the concerned zonal head of the medical workshop.

The zonal head appoints an engineer to the query and the CME releases a formal order to the engineer. The engineer is dispatched to the facility. On arrival, the engineer inspects the machine and if spare parts are not required, completes the maintenance process on the spot. The Engineer reports back to the authorities and the complaint ticket is closed. If spare parts are required, the engineer informs the facility and the facility is supposed to arrange for the parts. The complaint is put on a hold and once the parts are arranged, the engineer goes back to fix the equipment. Thereafter, a performa related to the repair is signed by the MS of the facility and the zonal head (in the case of maintenance with or without spares) to confirm the successful completion of the maintenance complaint. This performa is sent to the CME who updates the database and cross verifies the equipment status from the engineer. If the engineer fails to repair the equipment, the CME is notified and third party vendors are engaged. Lastly, if equipment is irreparable, condemnation of equipment takes place and the CME updates the database accordingly.

The maintenance activity therefore, is a combination of central and regional level resources managed at the top of the hierarchy, through a maintenance regime set by strategic level decisions. The maintenance itself is done as per the tactical framework, under which the facility and higher level management/resources are involved. The equipment information and complaint data comes from the bottom (facilities) but the decisions and SOPs are made at the top level.

Strategic, Tactical, and Operational Decisions for Equipment Maintenance

Decisions regarding equipment maintenance, trainings, resource planning, choice of maintenance options and developing infrastructure have a hierarchical nature depending on their importance to the organization. The most important decisions that set the policy framework for equipment maintenance are categorized as the strategic decisions, the mid-level decisions that execute the policy framework and formulate the operational framework for up-to-date maintenance can be seen as the tactical decisions, and the short term decisions that are made to ensure the day to day functioning of BERC and in-house equipment maintenance through resource and staff management are the operational decisions.

In case of biomedical equipment maintenance in Punjab, the decision to create a centralized maintenance regime in the form of a centralized biomedical equipment resource center (BERC) was a strategic decision. Details about its location, setting its responsibilities and designing its core values can be seen as policy level decisions that were made over a timeframe of 2-3 years. These decisions also involved number of staff and HR to hire, number and type of resources to acquire and to decide which type of maintenance practices/options will be available for BERC and the facilities to choose from. It was decided that the three medical workshops in Lahore, Multan and Sargodha will report to BERC and will be one of the resources used for maintenance. Apart from the medical workshops, mobile workshops along with BERC engineers, third party vendors and OEMs would be used for maintenance purposes based on the nature and requirements of the maintenance complaint. All these decisions are of strategic importance and hence, categorized as strategic decisions.

The decisions regarding which maintenance option to choose according to the situation, which engineer or resources to employ, making the SOPs for BERC, maintaining the CMMS database and setting up a framework for carrying out the maintenance process by adhering to the strategic decisions already made, were made over a period of a few months by top and mid-level management, and thus, are categorized as tactical decisions.

Carrying out the operational framework, updating the database by collecting data and performing the maintenance tasks are the day to day operations of the concerned authorities. Decisions regarding managing the relevant HR, using resources efficiently and keeping a track of the maintenance updates are weekly decisions that are categorized as operational decisions.

Equipment Maintenance Planning and Execution Under P&SHD

In the primary and secondary healthcare department, decisions and maintenance tasks are performed by different management levels. The table below shows how the equipment maintenance is done through hierarchical planning via the different tiers of management.

The top level management, that is the P&SHD secretariat, takes the policy and strategic level decisions. For example, all the decisions regarding the creation, governance and objectives of BERC along with maintenance options to be used were made at this level. Apart from making the strategy, the secretariat also gets involved in some tactical and operational decision making by overseeing the progress at all levels, forming frameworks and approving KPIs (See Table 9).

The tactical decisions concerning the choice of maintenance option, management and SOPs of different components of BERC and formulating operational tasks and accountability are taken by BERC- the mid-level body that was created as a tactical and operational arm for all equipment related concerns. BERC with approvals from the top-level not only par takes in important strategic decisions, but also carries out operational tasks, conducts maintenance and sets KPIs.

The health facilities, that is, BHUs and RHCs at the primary level and DHQs and THQs at the secondary level form the low-level management. These facilities are mostly involved in executing the frameworks set by the higher authorities. They do not take any strategic level decisions, however, they may sometimes get involved in tactical decisions by deciding how to manage their local HR and resources (See Table 9).

Information and Coordination for Equipment Maintenance

Equipment maintenance is done through centralized as well as decentralized options which results in a greater need for coordination for ensuring a smooth information flow between all stakeholders for timely and high quality maintenance of biomedical equipment. This not only involves inter-departmental coordination but also requires top-down and bottom-up information flow and communication. In order to achieve transparency, clear communication and timely information sharing, IT systems like email servers, file repository, drop box, online web portal, data reports and mobile apps prepared by HISDU are used at the facility, BERC and the secretariat level. All these tools are used to enhance coordination between departments and different management levels, which helps keep everyone on the same page.

Table 9. Hierarchical planning matrix for supply chain management

	Top Level: **P&SHD Secretariat**	**Mid-Level:** **BERC (tactical and Operational arm)**	**Low-Level:** **Health Facilities (Primary and Secondary)**
Strategic	➢ Set and formulate Maintenance infrastructure like Medical workshops, mobile workshops, BERC and HR requirements ➢ Policy decisions and reform: location of workshops, number of mobile workshops to be procured, type and quantity of HR hired) ➢ Decide on the organization, function and resources of BERC ➢ Engage 3rd party maintenance suppliers	➢ Input in BERC setup and formulation of agendas: o Call center operations o CMMS development o Inspections o Data collection o Trainings and contract management ➢ Propose and execute KPIs and Sops related to equipment repair	
Tactical	➢ Set framework for which options to be made available for maintenance practices: Workshops, OEMs, 3rd party, in-house capacity building	➢ Execute the supply chain framework ➢ Setting up policy framework for spare parts inventory management ➢ Management of call center, CMMS, workshops and HR/staff ➢ Framework for maintenance option to be chosen	➢ Manage Human Resource involved: o MS, admin officer and in-house engineers ➢ Local market and supplier information
Operational	➢ Approve operational level KPIs regarding corrective and preventative maintenance ➢ Set targets for establishment of maintenance regime	➢ Carrying out repair and maintenance ➢ Managing spare parts ➢ Keeping database updated via call center and CMMS ➢ Track complaints and data collection ➢ Conduct trainings and inspections ➢ Estimation and reporting of KPIs	➢ Execute maintenance as per choice framework through lesioning with BERC and local suppliers ➢ Maintenance of operational records ➢ Execute maintenance if 3rd party/local suppliers chosen for maintenance

Information flows in a top-down as well as a bottom up route, with decisions mainly only from a top-down approach. Complaint and equipment information is collected and reported from the facility using mobile app, web portal and text messaging service to the BERC. Database maintenance through CMMS and call center is done at BERC, which is then shared with higher authorities and hospital Medical Superintendents of facilities. Moreover, file repository, email servers and internet that connects all medical workshops, mobile workshops, BERC engineers and the BERC headquarters is also done and managed at BERC for seamless coordination and to ensure that everyone within BERC has access to same information. Reports and data regarding complaint management is then shared with higher authorities to maintain transparency at all levels.

At the facility, a point of contact is set to coordinate with on a regular basis. This point of contact is usually an administrative officer or a biomedical engineer deputed by the P&SHD secretariat. Within BERC, information flows in a vertical as well as a horizontal way. While all information regarding equipment status and complaints is collected and updated by the call center and fed into the CMMS, everyone directly reports to the chief technical officer (CTO) BERC through department heads. This maintains an open information flow between all levels at BERC. All information is shared with the Secretary, Additional Secretaries and District health authorities at conferences, weekly reviews and daily meetings. Similarly, decisions taken at the top are communicated downwards, and information regarding progress, feedback or possible problem areas are shared from both ends.

Aggregation in Hierarchical Equipment Maintenance Structure

One way to achieve better coordination is through integration and consolidation of different units and systems in the department. Aggregating information, functions and implementation through partnerships and joint responsibilities/execution for maintenance of equipment by forming a single aggregate unit to perform collective tasks in order to reduce any chances of asymmetric information or bullwhip effect can be seen in the maintenance structure at hand.

The call center, OEMs, Third party-vendors and mobile and medical workshops along with BERC engineers act as the maintenance options and are used collectively depending on the need and complexity of the situation. The joint efforts and same function of maintaining biomedical equipment make them into an aggregate maintenance unit. If one option/unit is unable to repair, the second and then the third takes over as explained in the Figure 7. Similarly, the Monitoring and evaluation Associates (MEAs), BERC engineers, BERC training center, facility point of contact and call center act as one unit for the collection of data, database management, equipment information and capacity building through trainings and data sharing.

In terms of decision making, most of the strategic level decisions about what resources and how to use them are aggregated at the top and mid-level management. That is, the secretariat along with the Director and CTO of BERC, and procurement department specialist make aggregated decisions and choices regarding what maintenance options and resources to be made available, how and what to procure for better maintenance, and decisions about revamping and who to report to. Moreover, BERC and the procurement cell of P&SHD work closely to formulate SOPs, operational frameworks and best practice manuals. They also perform tasks like initial inspection, trainings and capacity building as an aggregate unit.

Lastly, the functions of District Health Authorities (DHAs) and how they decide and communicate on behalf of primary and sometimes secondary health facilities in their districts is another way that aggregation takes place. Each district has four secondary health facilities and around 60- 70 primary health facilities that report to the respective District Health Authority (DHA). Several functions and decisions regarding emergency equipment procurement or maintenance budgets and plans, additional equipment inspection or other relevant requests are made collectively at the district level and communicated/decided by the DHA. Once could see it as an example of aggregation according to geographical clustering.

Thus, information, functions and implementation are aggregated according to the need and situation at hand for higher coordination and better information flow in the biomedical maintenance structure that follows a hierarchical system of decision making and management levels.

Summary of the Cases

We have now discussed medicine and equipment maintenance supply chains at P&SHD. As discussed earlier, P&SHD is a hierarchically organized entity that aims to provide public healthcare services throughout the far flung area of the Punjab, Pakistan. It does so by organizing tiers of service delivery and organizational functions throughout the Punjab province. The tiers of service delivery consist of primary and secondary healthcare levels whereas the organizational hierarchy in the case of equipment maintenance consists of top level (i.e. P&SHD secretariat), mid-level (i.e. BERC) and low level (i.e. Health Facilities). Provision of accurate and timely information is strived for and aggregation of supply chain functions is utilized for efficient healthcare service delivery. We now discuss our conclusions in the next section.

CONCLUSION

We have now studied medicine and equipment maintenance supply chains at P&SHD in detail. Clearly the services provided by the P&SHD are extensive and require a complex service delivery structure to support the entire province of the Punjab. One can observe from the case of P&SHD that public healthcare system require hierarchically organization and healthcare supply chains follow many principles of hierarchical planning and execution as discussed in literature. We now outline key takeaways from our discussion in the previous sections:

- Complexity of the public healthcare service delivery supply chains is managed through hierarchical organization of supply chain functions. This is especially relevant for public healthcare services systems where services are hierarchically organized under primary and secondary healthcare levels and entail geographical distribution of services to meet the healthcare requirements of entire population.
- One can observe from the literature review and case studies that strategic supply chain decisions are managed at higher echelons of the hierarchical organization whereas tactical and operational decisions are managed at mid and lower echelons of the hierarchically organized structure respectively.
- To facilitate the uniformity and simplification of the supply chain decision making, principle of aggregations is utilized to establish the specialty of decision making functions at various levels of the hierarchical structure.
- Accurate and timely Information is important impetus for quick and efficient supply chain decision making in a hierarchically organized supply chain structure. Conversely, hierarchically organized public healthcare supply chains are highly susceptible to inefficiencies in the presence of supply chain information symmetry.
- In the case of primary and secondary healthcare, it is the hierarchical organization of medicine and equipment maintenance supply chains that allows P&SHD to provide primary and secondary healthcare services at geographically dispersed far flung areas.
- P&SHD should strive for improvements in its information technology infrastructure to reduce information asymmetries and inculcate further efficiencies in its medicine and equipment maintenance supply chains.

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Chapter 4
Impact of Green Supply Chain Management on Competitive Advantage of Business Organizations in Sri Lanka

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ABSTRACT

Organizations adopt many strategies to gain competitive advantage. An important strategy is adopting green practices. Cost-benefit and customer value enhancement are two other strategies. By combining all of these elements, organizations can acquire a superior competitive advantage. There are contradictory findings on applying the cost-benefit element to green supply chain management (GSCM) and no clear theory on how to combine these elements to gain a competitive advantage. The primary objective of this study is to identify the impact of GSCM on competitive advantage of business organizations in Sri Lanka. Sample technique used was convenience sampling method. Data was collected from 30 organizations that were following green practices in Sri Lanka. The data were analyzed using descriptive analysis, correlation coefficient, and simple regression model. The results show that there is a strong positive relationship between GSCM and competitive advantage, and rather than applying just one element to gain a competitive advantage, it was considered more effective to apply both cost-benefit and customer value enhancement simultaneously.

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INTRODUCTION

Strategic management is the careful examination of an action plan to determine how it will help to develop and regulate the competitive advantage of a business organization. The measure of the competitive advantage is the difference between the organization's and its competitors' position (Mintzberg & Quinn, 1991).

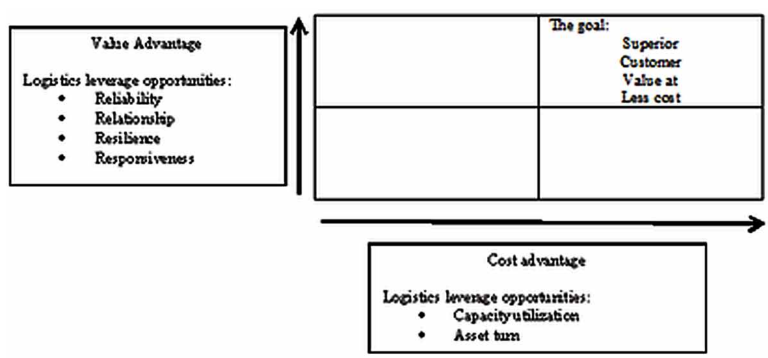
The capability of a business organization to create an unassailable position over its competitors can be defined as competitive advantage (Li *et al*., 2006). There are many factors that can contribute to gain a competitive advantage over other firms – the formation of higher competencies that are leveraged to generate customer value, achieving higher cost-effectiveness, and possessing differentiation advantages, which will result in a bigger market share and cost savings (Barney, 1991; Day & Wensley, 1988; Prahalad & Hamel, 1990).

BACKGROUND

According to Martin Christopher (2011), to gain a competitive advantage the organization should have value advantage and cost advantage.

Further, as per Porter's theory, an organization's competitive advantage hinges on its capability to be a low-cost producer in its industry or to be unique in its industry in those features that are popularly valued by consumers (Porter, 1991). Most executives agree that cost and value will determine the strength of a firm's competitive advantage (D' Souza & Williams, 2000).

Figure 1. Gaining competitive advantage
Source: Logistic and supply chain management, 4th edition by Martin Christopher



The important competitive capabilities have been identified as price or cost, quality, supply chain management, and time (Vokurka *et al*., 2002). Supply chain management (SCM) plays an important role in helping firms to gain competitive advantage (Mentzer *et al*., 2001). SCM starts with the purchase of raw materials, and applied consistently to the many production activities that change raw materials into the finished product and until it is finally delivered to consumers through a distribution system (Lee & Billington, 1995). The actual competition will not be among business organizations but among supply chains. An organization's competitive advantage is dependent on its overall production system and that includes decisions it makes about activities in its value chain (Haytko & Kent, 2007; Porter, 1990).

Organizations that led the way in green innovations enjoy the first major advantage. Primary initiatives helped them develop fresh markets, gain competitive advantages and command a higher price for green products (Chen, Lai & Wen, 2006). Being eco-friendly is one way to differentiate them from their competitors. So, due to their commitment to environmental issues, the green businesses stand out from others and enjoy better corporate images. Green Supply Chain Management (GSCM) combines green thinking into SCM, including product design, material sourcing and selection, manufacturing processes, and delivery of the final products to the consumers. Supply chain executives have to balance their efforts to lessen costs against their efforts to innovate while maintaining good eco-friendly performance (Pagell *et al*., 2004). GSCM has emerged as a method to balance these competing priorities (Narasimhan & Carter, 1998). Currently, environmental pollution is the key issue that threatens the future of mankind on Earth, so it is imperative to address it instantly. Srivastava (2007) defined GSCM as integrating environmental priorities into SCM, which was inextricably linked with product and service design, procurement, manufacturing processes, distribution, and end-of-life management of the product to achieve a sustainable competitive advantage. Therefore, the primary objective is to identify the Impact of Green Supply Chain Management on Competitive Advantage of Business Organizations in Sri Lanka.

LITERATURE SURVEY

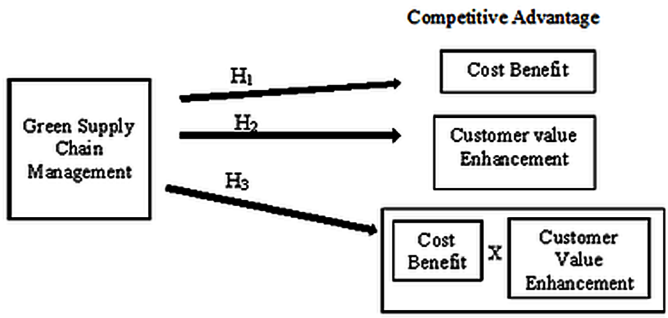
SCM plays a central role in an organization's global competitiveness. A supply chain is a linkage of buyers and suppliers (Choi & Hong, 2002), which is built up to increase the competitive advantage of a firm by enabling it to coordinate with its partner organizations' processes, expertise, and competencies (Farley, 1997). Many researchers and practitioners have attempted to find the various factors that affect GSCM either positively or negatively. With almost all countries being concerned about sustainability, GSCM has emerged as a relevant topic with sustainable

SCM, which describes the environmental management during production of goods or services, ethically and fairly along the supply chain (Walker & Jones, 2012). In the current context of globalization, environmental issues have become very important for organizations that wish to maintain their competitiveness. Therefore, most businesses are endeavoring to make their supply chains even more efficient and green. Ecological management is gaining attention among SCM researchers (Subramanian & Gunasekaran, 2015). Handfield and Nichols (1999) have declared that greening of the supply chain will become an important issue in the near future. Singh and Sharma (2015) have observed that to make the supply chain competitive, organizations should adopt more energy efficient and sustainable methods. Green supply chain approaches have proved to be a source of strength for many business organizations. Stonebraker and Afifi (2004) have found that management's ability to recognize changes in the competitive environment is crucial for the success of a strategic supply chain. Therefore, direct and coordinated action is needed across the organizations linked to a supply chain to utilize resources effectively and meet the demands of environmental issues (Singh, 2013). Mangla *et al.* (2015) have observed that green supply chain management involves many operational risks. For example, there are some contradictory findings regarding GSCM and the cost efficiency of organizations following same.

According to Wycherly (1999), there are some fundamental obstacles to adopting a GSCM approach, such as increased costs, unreliable suppliers, insufficient information, lack of resources, inadequate expertise of suppliers and poor government policies. Mainly, the barriers are related to weak management, outdated technology, environmental degradation, lack of employee involvement and ill-defined government policies. Several organizations have failed to consolidate their green supply chain because they deployed inadequate measures and metrics (Mentzer *et al.*, 2007). Considering all of that the researchers concluded that a knowledge gap existed because it was not possible to reach a proper conclusion as to whether adopting green practices would increase or decrease the cost efficiency of organizations. Based on the gaps in literature, the researchers observed that many organizations faced problems in successfully implementing GSCM to gain competitive advantage. There is little interest in conducting studies on GSCM in developing countries unlike in the case of developed countries (Jayaram & Avittathur, 2012). Therefore, the key objectives of this paper are to identify the impact of GSCM on competitive advantage of firms on the basis of the literature review and to develop a structural framework for implementing GSCM successfully.

Diagram in Figure 2 shows the conceptual framework of the study.

Figure 2. Conceptual model
Source: Based on Literature



- **H1:** There is a positive relationship between GSCM and cost-benefit of organization
- **H2:** There is a positive relationship between GSCM and customer value enhancement
- **H3:** There is a positive relationship between GSCM and combined competitive advantage elements of organizations

To identify the impact of Green Supply Chain Management on Competitive advantage, simple regression analysis was used.

METHODOLOGY

The current study follows the quantitative deductive approach. Further, according to the Central Bank of Sri Lanka Report (2011), there are only a few industries that are earnestly practicing GSCM in Sri Lanka. The sample was taken to be representative of those industries in Sri Lanka that are practicing green supply chain management; as such, this study picked out 30 business organizations that had adopted this practice.

The research used both primary as well as secondary sources of information. As for primary information, the main source was the survey questionnaire while the secondary information was obtained from the works of published authors. The primary data was collected through questionnaires for this research work as that is the easiest and most cost-effective way of obtaining information from office employees. The response to the questions had to be marked on a seven-point Likert scale. The scale ranged from 'strongly agree' = 7 to 'strongly disagree' = 1.

To identify the dimensions of cost-benefit, secondary data were gathered. The secondary data were expressed as percentage values but they were also converted into a seven-point scale for ease of analysis. The percentage values were converted into a seven-point scale by dividing 100 by 7 and then multiplying the answer by 1, 2, 3, 4, 5, 6 or 7, respectively. Thus, any value between 0% and 14.2857% was equal to 1 on the Likert scale. Any value between 14.2857% and 28.5714% was equal to 2 on the Likert scale and so on, with any value between 85.7143 and 100 being equal to 7.

Apart from that, descriptive statistics were used to assess existing green supply chain management practices in business organizations in Sri Lanka. Karl Pearson correlation was used to assess the relationship between supply chain practices and competitive advantage elements. Further, simple regression analysis was used to determine the impact of green supply chain management practices on competitive advantage elements, both individually and in combination.

FINDINGS AND DISCUSSION

Objective 1: To determine the existing green supply chain management practices followed by Sri Lankan business organizations

The first objective was to determine the existing green supply chain management practices followed by Sri Lankan business organizations. To achieve this objective descriptive analysis was used. Descriptive statistics were run on responses to the 30 substantive 7-point scale items.

Descriptive Analysis of Variables

The researchers used the descriptive technique for the interpretation of data to identify the existing Green Supply Chain Management practices. The analysis depended on such values as mean and standard deviation for interpretation of the data.

According to Table 1, the mean of green supply chain management variable was 4.1792. This value implied that the Green Supply Chain Management variable is moderate. According to Table 1, the mean values for cost-benefit and customer value enhancement are 4.4333 and 4.2688, respectively. It implies that business organizations in Sri Lanka agree to some extent that they are following green practices in supply chain management, gain cost-benefit and gain customer value enhancement. The highest mean value belongs to cost-benefit.

Table 1. Descriptive Statistics of variables

	Mean	Standard deviation	Skewness	Kurtosis
Green Supply Chain Management (GSCM)	4.1792	0.59513	-0.761	2.101
Cost-benefit (CB)	4.4333	0.95352	-0.755	1.958
Customer Value Enhancement (CVE)	4..2688	0.52168	0.001	0.271

Source: SPSS output from field information

In addition to that, the standard deviation indicates how data are scattered about the mean. On the other hand, it measured how far a value ranged away from the mean. According to Table 1, value of standard deviation for Green Supply Chain Management is 0.59513. The standard deviation for cost-benefit is 0.95352 and standard deviation for customer value enhancement is 0.52168. Therefore, this implies that there were no great deviations from the mean value for both Green Supply Chain Management and Customer Value Enhancement. Smaller standard deviation indicates that more of the data was clustered about the mean. But if there is a high standard deviation for cost-benefit it means the data are more widely scattered.

The competitive advantages of different types of GSCM practices need to be clear in order to encourage firms to implement a wider variety of GSCM initiatives. One of the main messages to practitioners is that the financial performance of a firm can be improved while also reducing negative effects on the natural environment; thus, if the right type of GSCM is chosen it simply means better cost-benefit. In order to achieve environmental, operational and financial performance benefits, firms should combine internal GSCM practices with activities targeted towards external supply chain partners, such as suppliers and customers. This study suggests that many firms might forget the importance of external activities while pursuing internal environmental initiatives vigorously. Firms need to extend their focus beyond organizational boundaries to benefit fully from GSCM adoption. As explained in this thesis, internal GSCM practices in combination with a stricter environmental monitoring-based approach towards suppliers are the most effective way to gain competitive advantage.

Objective 2: To identify the relationship between green supply chain management and cost-benefit, value enhancement

To achieve the second objective of the study, the researchers used Karl Pearson Correlation analysis. According to the p values, results are highly significant. The study results indicate that there is a relationship between green supply chain management and cost-benefit, green supply chain management and customer value enhancement, and green supply chain management and total competitive advantage. All these relationships are strong positive relationships and the highest Pearson correlation value is 0.880 when green supply chain management is combined with competitive advantage. Mean value of both cost-benefit and customer value enhancement reflect the combined competitive advantage. With all that to secure a better competitive advantage, it is essential to have cost-benefit and customer value enhancement together because they both have the highest relationship with green supply chain management.

In statistics, the correlation coefficient 'r' measures the strength and direction of a linear relationship between two variables on a scatterplot. The value of r is always between +1 and –1.

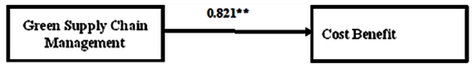
Correlation Between Green Supply Chain Management and Cost-Benefit

This study used the Pearson correlation to identify the relationship between green supply chain management and cost-benefit of organizations.

According to Figure 3, the correlation between green supply chain management and cost-benefit is 0.821. It denotes that there is a strong positive linear relationship between the independent and dependent variables. In addition, the significance of the P value was at zero level ($0.000 < 0.05$). The probability of association between

Figure 3. Relationship between Green Supply Chain Management and Cost-benefit
Source: SPSS output from field survey.

Figure 4. Correlation between Green Supply Chain Management and Cost-benefit
Source: SPSS output from field survey



Green Supply Chain Management and Cost-benefit is 0.000. As this is less than 1% it denotes that the results are highly significant. Hence, this is supported by the relationship. Therefore, the null hypothesis (H0) is rejected and the alternative hypothesis (H1) at 95% confidence level is accepted. It means there is a relationship between Green Supply Chain Management and Cost-benefit. When considering the overall results it can be demonstrated that there is a highly significant and strong positive association between Green Supply Chain Management and Cost-benefit.

Correlation Between Green Supply Chain Management and Customer Value Enhancement

Figure 5 elaborates on the relationship between Green Supply Chain Management and Customer Value Enhancement through a scatterplot diagram.

Therefore, in accordance with these findings we could hypothesize as follows:

Figure 5. Relationship between Green Supply Chain Management and Customer Value Enhancement
Source: SPSS output from field survey.

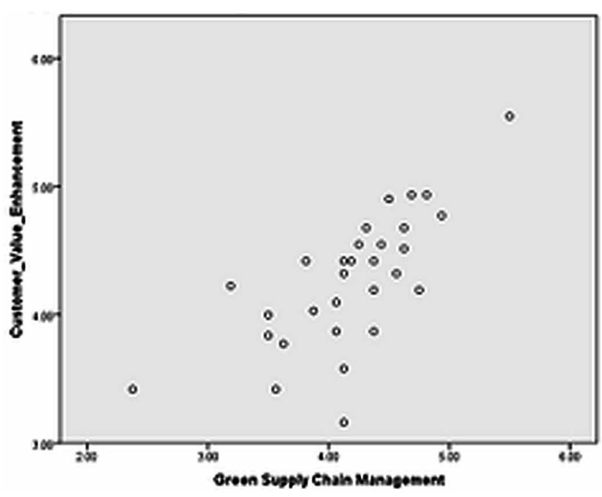
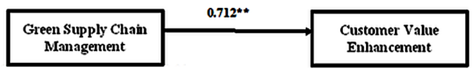


Figure 6. Correlation between Green Supply Chain Management and Customer Value Enhancement
Source: Based on the analyzed data



H_2: There is a positive relationship between Green Supply Chain Management and Customer Value Enhancement.

According to the data, the correlation between Green Supply Chain Management and Customer Value Enhancement is 0.712. Hence, there is a strong positive linear relationship between these two variables with significance of P-value at 0.000, which implies that the test is highly significant. Therefore, the null hypothesis (H_0) is rejected and the alternative hypothesis there is a positive relationship between Green Supply Chain Management and Customer Value Enhancement is accepted. (H_2) is at the 95% confidence level. Overall results demonstrated that there is a significant and positive association between Green Supply Chain Management and Customer Value Enhancement.

Correlation Between Green Supply Chain Management and Combined Competitive Advantage Elements

In accordance with the findings of Chapter 02,

H_3: There is a positive relationship between Green Supply Chain Management and Total Competitive Advantage.

The correlation coefficient of Green Supply Chain Management and combined competitive advantage is 0.880 and this represents a strong positive relationship. It implies that there is a significant influence of Green Supply Chain Management on combined Competitive Advantage. As per the figure, the data supports a statistically significant relationship ($P < 0.05$). Therefore, it rejects the null hypothesis (H_0) and accepts the alternative hypothesis (H_3) at 95% confidence level. Overall results demonstrated that there is a significant and positive association between Green Supply Chain Management and Combined Competitive Advantage.

The Highest Pearson correlation value of 0.880 is to Green Supply Chain Management and combined Competitive Advantage. The lowest value of 0.712 is to Green Supply Chain Management and to Customer Value Enhancement.

Figure 7. Relationship between Green Supply Chain Management and Combined Competitive Advantage elements
Source: SPSS output from field survey.

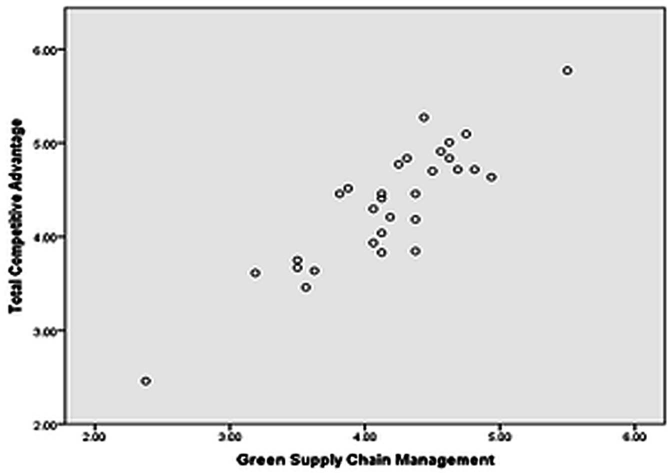
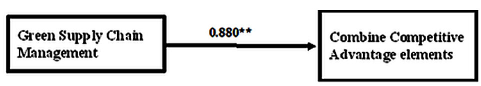


Figure 8. Correlation between Green Supply Chain Management and Combined Competitive Advantage elements
Source: Based on the analyzed data



When comparing the aforementioned three situations, Green Supply Chain Management and combined Competitive advantage have a high Pearson Correlation value of 0.880 which is very close to 1. This means that changes in Green Supply Chain Management variable are strongly correlated with changes in combined Competitive Advantage variable. Meanwhile, Green Supply Chain Management and Customer Value Enhancement Pearson Correlation value is 0.712 which is rather less than 1. Compared to the other two Pearson Correlation values it is quite small. It denotes that changes in Green Supply Chain Management and Customer Value Enhancement are correlated but not as strongly as with the other two dependent variables.

The summary of correlation analysis of the study demonstrates that Green Supply Chain Management has a strong positive relationship with Cost-benefit and Customer Value Enhancement, both separately and acting in combination.

Table 2. Summary of Correlation Analysis with Hypothesis

	P– Value<Significance Level	Relationship	Null Hypothesis (H0)	Alternative Hypothesis (Ha)
Green Supply Chain Management and Cost-benefit	0.000 < 0.821	Strong Positive	Rejected	Accepted
Green Supply Chain Management and Customer Value Enhancement	0.000 < 0.712	Strong Positive	Rejected	Accepted
Green Supply Chain Management and combined Competitive Advantage elements	0.000 < 0.880	Strong Positive	Rejected	Accepted

Source: SPSS output from field information

According to Wycherly (1999), there are some fundamental barriers that may be encountered after adopting the GSCM path, such as increased costs, unreliable suppliers, lack of information, lack of resources, inadequate expertise of suppliers and hard to fathom government policies. Mainly, the barriers are related to management, technology, environmental issues, lack of employee involvement and unclear government policies. Several organizations have failed to consolidate their green supply chain because they deployed inadequate measures and metrics (Mentzer *et al*., 2007). But according to current research findings, Green Supply Chain Management practices can contribute positively to cost-benefit in Sri Lankan business organizations. A positive relationship between Green Supply Chain Management and cost-benefit has been confirmed.

Simple Regression Analysis

Green Supply Chain Management and Cost-Benefit

According to this research, the dependent variable is Cost-benefit and the independent variable is Green Supply Chain Management. Based on the primary research objective the simple linear regression model is derived as shown in Table 3.

Where,

Table 3. Regression analysis equation

$CB = \beta0 + \beta1\ GSCM + \varepsilon$

Source: Based on the primary data

GSCM = Green Supply Chain Management
CB = Cost-benefit
Ɛ = Standard Error
β0, β1 = Slopes of the curve

Results of Regression Analysis

Based on the regression analysis information given in Table 3 the regression equation can be expressed as shown in Table 5.

Where,

GSCM = Green Supply Chain Management
CB = Cost-benefit
Ɛ = Standard Error

Scatter plot related to the regression analysis is shown in Figure 9.

In accordance with the regression equation, the constant value is -1.065. It implies that if there is no green supply chain management, there is no cost-benefit. The constant gets the value of -1.065 for the Cost-benefit when the Green Supply Chain Management is equal to the zero level. Furthermore, the coefficient of Green Supply Chain Management is +1.316. It is the average change that occurs in Cost-benefit when there is a one unit change in Green Supply Chain Management. It suggests that when the Green Supply Chain Management increased by one unit, Cost-benefit

Table 4. Regression analysis of Green Supply Chain Management and Cost-benefit

Model	B	Standard Error	t-value	p-value
Constant	-1.065	0.729	-1.461	0.155
Green Supply Chain Management	1.316	0.173	7.616	0.000

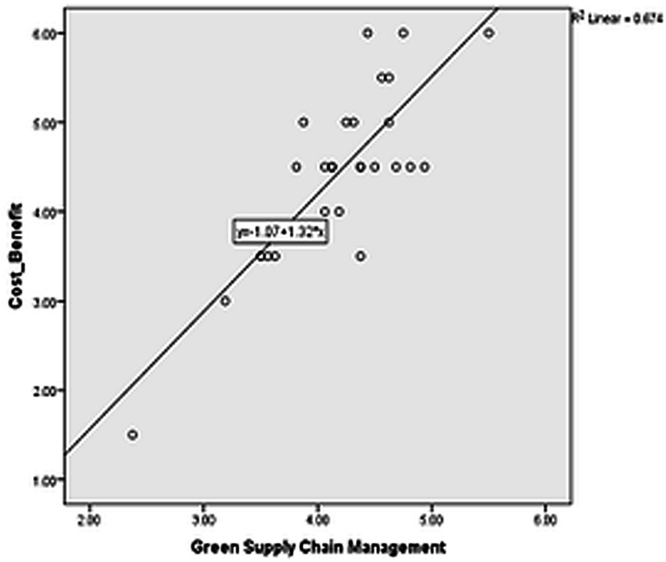
Source: SPSS output from field information
Dependent variable: Cost-benefit

Table 5. Regression analysis equation

CB = -1.065 + 1.316GSCM+Ɛ

Source: SPSS output from field information

Figure 9. Scatter plot of Green Supply Chain Management and Cost Benefit
Source: SPSS output from field survey.



increased by 1.32. In addition to that, it implies that there is a positive relationship between green supply chain management and cost-benefit.

Results of the linear regression analysis are given in Table 4 and the results indicate the impact of Green Supply Chain Management on Cost-benefit. According to the outcome of the regression model, Green Supply Chain Management variable will indicate the status of its significance ($p < 0.05$).

Model Summary

The coefficient of determination (R2) measures the goodness of fit of the regression line to the set of data. It describes the R2 value of the model as a measure of the proportion or percentage of total variation of the dependent variable, which is explained by the independent variables. When considering the linear regression model summary the R2 value was 0.674. The proportion of the dependent variable covered by the regression model is explained by R2. If this value is 0.6 or more, the model can be considered a good fit. Even if this value is somewhat lower, the model can be used as R2 belongs to sum. According to this research, the model is well fitted. Therefore, it can be concluded that 67.4% of the total variation in Cost-benefit is explained by the Green Supply Chain Management. On the other hand, 32.6% of total variance in the Cost-benefit is not explained by the linear regression

Table 6. Model summary for linear regression analysis

Figure	Value
R	0.821
R Square	0.674
Adjusted R Square	0.663
Std. Error of the Estimates	0.55371

Source: SPSS output from field survey.

model. Therefore, it appears that the model was fitted in a fairly satisfactory manner. Because of that, the unexplained variation is less than the explained variation.

Researches often use more independent variables than necessary. But in this study R2 has a tendency to increase and therefore it should be adjusted using another coefficient. After adjustment the R2 value was 0.663 and standard error of estimate was 0.55371. According to the adjusted R2 result, 66.3% has been covered by the model. It implies that the data have deviated from the fitted line of regression.

The Overall Significance of the Model

Analysis of variance is presented in Table 6 and it includes the sum of square, degree of freedom, F value and P value and is presented to confirm the overall significance of the model.

In accordance with the F value condition, it should be greater than the F table value to be significant in the overall model. It can be illustrated as F ratio > F table value. As per Table 6, the F value was 57.997. When compared with the F table, its value was 4.20 at 0.05 significant level ($\alpha = 0.05$). Therefore, the calculated F value was greater than the F table value.

Condition of F ratio: > F table value
57.997 > 4.20

Table 7. ANOVA Results

Model	DF	Mean Square	F value	P value
Regression	1	17.782	57.997	0.000
Residual	28	0.307		
Total	29			

Source: SPSS output from field survey.

Therefore, the null hypothesis is rejected. The results demonstrate that the regression is meaningful and that the overall model can be applied statistically to predict the dependent variable.

Green Supply Chain Management and Customer Value Enhancement

In this research the dependent variable is Customer Value Enhancement and the independent variable is Green Supply Chain Management. Based on the primary research objective the simple linear regression model is derived as shown in Table 8.

Where,

GSCM = Green Supply Chain Management
CVE = Customer Value Enhancement
Ɛ = Standard Error
B2, β3 = Slopes of the curve

Results of Regression Analysis

Based on the regression analysis information given in Table 9 the regression equation can be expressed as shown in Table 10.

Where,

GSCM = Green Supply Chain Management

Table 8. Regression analysis equation

$CVE = \beta 2 + \beta 3\ GSCM + \varepsilon$

Source: Based on the primary data

Table 9. Regression analysis of Green Supply Chain Management and Customer Value Enhancement

Model	B	Standard Error	t-value	p-value
Constant	1.661	0.491	3.383	0.002
Green Supply Chain Management	0.624	0.116	5.364	0.000

Source: SPSS output from field information
Dependent variable: Customer Value Enhancement

Table 10 Regression analysis equation

CVE = 1.661 + 0.624GSCM+Ɛ

Source: SPSS output from field information

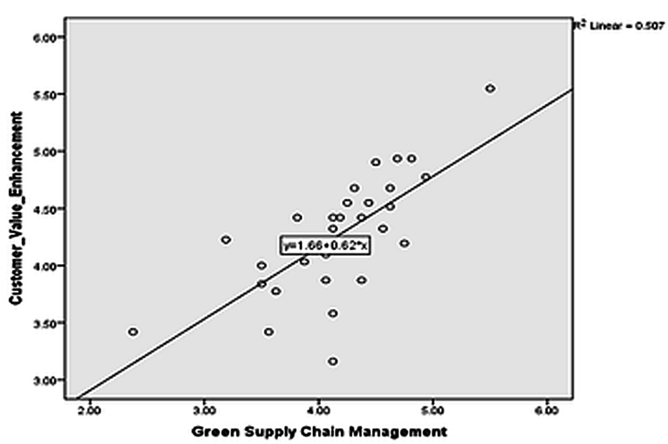
CVE = Customer Value Enhancement
Ɛ = Standard Error

Scatter plot related to the regression analysis is shown in Figure 10.

In accordance with the regression equation, the constant value is 1.661. It refers to the value of Customer Value Enhancement when the Green Supply Chain Management is equal to the zero level. Furthermore, the coefficient of Green Supply Chain Management is +0.624. It is the average change that occurs in Customer Value Enhancement when there is a one unit change in Green Supply Chain Management. It suggests that when Green Supply Chain Management increases by one unit, Customer Value Enhancement increases by 0.624. In addition to that, it implies that there is a positive relationship between green supply chain management and Customer Value Enhancement.

Results of the linear regression analysis are given in Table 8 and they indicate the impact of Green Supply Chain Management on Customer Value Enhancement. According to the outcome of the regression model, the Green Supply Chain Management variable indicates the status of significance ($p < 0.05$).

Figure 10. Scatter plot of Green Supply Chain Management and Customer Value Enhancement
Source: SPSS output from field survey.



Model Summary

The coefficient of determination (R2) measures the goodness of fit of the regression line to the set of data. It describes the R2 value of the model as a measure of the proportion or percentage of total variation of the dependent variable, which is explained by the independent variables. When considering the linear regression model summary the R2 value was 0.507. In accordance with that, it can be concluded that 50.7% of the total variation of Customer Value Enhancement is explained by Green Supply Chain Management. On the other hand, 49.3% of total variance in the Customer Value Enhancement is not explained by the linear regression model. Therefore, it appears that the model was fitted in a fairly satisfactory manner. Because of that, the unexplained variation is less than the explained variation.

Further, the adjusted R2 value was 0.489 and standard error of estimate was 0.37284. It indicates how data deviated from the fitted line of regression. According to the adjusted R2 results, 48.9% was predicted by the model.

Overall Significance of the Model

Analysis of variance is presented in Table 12 and it shows sum of square, degree of freedom, F value and P value to indicate the overall significance of the model.

In accordance with the F value condition, it should be greater than the F table value to be significant in the overall model. It can be illustrated as F ratio > F table value. As per Table 11, the F value is 28.776. When compared with the F table value,

Table 11. Model summary for linear regression analysis

Figure	Value
R	**0.712**
R Square	**0.507**
Adjusted R Square	**0.489**
Std. Error of the Estimate	**0.37284**

Source: SPSS output from field survey.

Table 12. ANOVA Results

Model	DF	Mean Square	F value	P value
Regression	1	4.000	28.776	0.000
Residual	28	0.139		
Total	29			

Source: SPSS output from field survey.

the value was 4.20 at 0.05 significant level ($\alpha = 0.05$). Therefore, the calculated F value was greater than the F table value.

Condition of F ratio > F table value
28.776 > 4.20

Therefore, the null hypothesis is rejected. The results demonstrate that the regression is meaningful and the overall model can be applied statistically to predict the dependent variable.

Green Supply Chain Management and Combined Competitive Advantage

According to this research the dependent variable is for both cost-benefit and customer value enhancement while the independent variable is Green Supply Chain Management. Based on the primary research objective the simple linear regression model is derived as follows:

Where,

GSCM = Green Supply Chain Management
CB X CVE = Combined Competitive Advantage
Ɛ = Standard Error
B4, β5 = Slopes of the curve

Results of Regression Analysis

Based on the regression analysis information given in Table 14 the regression equation can be expressed as shown in Table 15.

Where,

GSCM = Green Supply Chain Management
CB X CVE = Combined Competitive Advantage
Ɛ = Standard Error

Scatter plot of the regression analysis is shown in Figure 11.

Table 13. Regression analysis equation

CB X CVE = β4 + β5 GSCM+Ɛ

Source: Based on the primary data

Table 14. Regression analysis of Green Supply Chain Management and combined Cost-benefit and Customer Value Enhancement

Model	B	Standard Error	t-value	p-value
Constant	0.298	0.417	0.714	0.481
Green Supply Chain Management	0.970	0.099	9.815	0.000

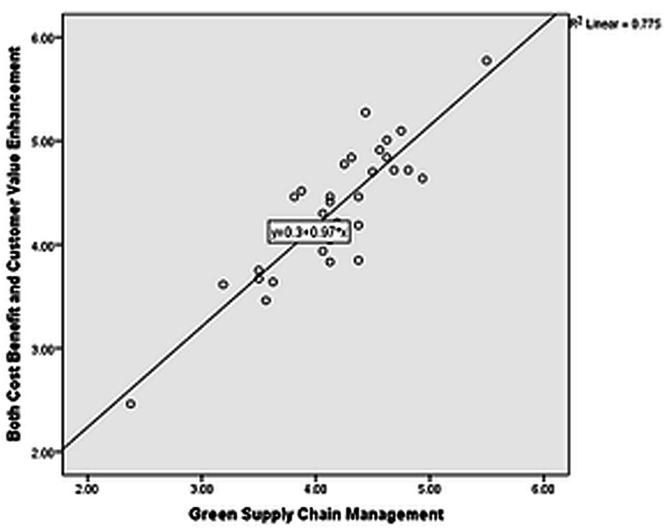
Source: SPSS output from field information
Dependent variable: Total Competitive Advantage

Table 15. Regression analysis equation

CB X CVE = 0.298 + 0.970GSCM + Ɛ

Source: SPSS output from field information

Figure 11. Scatter plot of Green Supply Chain Management and Combined Competitive Advantage
Source: SPSS output from field survey.



According to the regression equation, the constant value is +0.298. It indicates the value of both Cost-benefit and Customer Value Enhancement when the Green Supply Chain Management is equal to the zero level. Furthermore, the coefficient of Green Supply Chain Management is +0.970. It is the average change that occurs in both Cost-benefit and Customer Value Enhancement when there is a one unit change in Green Supply Chain Management. It means that when Green Supply

Chain Management increases by one unit, both Cost-benefit and Customer Value Enhancement increase by 0.970. In addition to that, it implies that there is a positive relationship between green supply chain management and both Cost-benefit and Customer Value Enhancement.

Results of the linear regression analysis are given in Table 14 and these indicate the impact of Green Supply Chain Management and both Cost-benefit and Customer Value Enhancement. According to the outcome of the regression model, the Green Supply Chain Management variable indicates the status of significance ($p < 0.05$).

Model Summary

The coefficient of determination (R2) measures the goodness of fit of the regression line to the set of data. It describes the R2 value of the model as a measure of the proportion or percentage of total variation of the dependent variable, which is explained by the independent variables. When considering the linear regression model summary the R2 value was 0.775. In accordance with that, it can be concluded that 77.5% of the total variation of both Cost-benefit and Customer Value Enhancement is explained by the Green Supply Chain Management. On the other hand, 22.5% of total variance in both Cost-benefit and Customer Value Enhancement is not explained by the linear regression model. Therefore, it appears that the model was fitted in a satisfactory manner. Because of that, the unexplained variation is less than the explained variation. Further, the adjusted R2 value was 0.767 and standard error of estimate was 0.31669. It indicates how data deviated from the fitted line of regression. Adjusted R2 result of 76.7% has been covered by the model.

Overall Significance of the Model

Analysis of variance is presented in Table 17 and includes degree of freedom, sum of square, F value and P value to indicate the overall significance of the model.

Table 16. Model summary for linear regression analysis

Figure	Value
R	0.880
R Square	0.775
Adjusted R Square	0.767
Std. Error of the Estimate	0.31669

Source: SPSS output from field survey.

Table 17. ANOVA Results

Model	DF	Mean Square	F value	P value
Regression	1	9.662	96.342	0.000
Residual	28	0.100		
Total	29			

Source: SPSS output from field survey.

In accordance with the F value condition, it should be greater than the F table value to be significant in the overall model. It can be illustrated as F ratio > F table value. As per Table 16, F value was 96.342. If it is compared to the F table value, the value was 4.20 at 0.05 significant levels ($\alpha = 0.05$). Therefore, the calculated F value was greater than the F table value.

Condition of F ratio > F table value
96.342 > 4.20

Therefore, the null hypothesis is rejected. It illustrates that the regression is meaningful and that the overall model can be applied statistically to predict the dependent variable.

Objective 3: To identify the green supply chain management's impact on cost-benefit and competitive advantage elements individually

To identify the green supply chain management's impact on competitive advantage in order to acquire a superior competitive advantage, researchers perform an analysis using simple linear regression. In simple linear regression, researchers consider the R2 value. This interprets the association between independent variables and the dependent variable. The coefficient of determination (R2) is shown in Table 18.

Table 18. Regression Analysis

		R^2
$CB = \beta 0 + \beta 1\ GSCM + \varepsilon$	$CB = -1.065 + 1.316GSCM + \varepsilon$	0.674
$CVE = \beta 2 + \beta 3\ GSCM + \varepsilon$	$CVE = 1.661 + 0.624GSCM + \varepsilon$	0.507

Source: SPSS output from field survey.

The coefficient of determination (R2) is 0.674 and 0.507 for cost-benefit and customer value enhancement, respectively. If the R2 value is 0.6 or more, the model can be considered well fitted. Even though this value is low, the model can be used as R2 belongs to sum. According to Table 17, cost-benefit shows the highest R2 value. There is a high impact on competitive advantage by both cost-benefit and customer value enhancement, but with cost-benefit exerting a greater impact than customer value enhancement.

According to the literature, Handfield and Nichols (1999) have suggested that greening of the supply chain will become a critical issue in the near future scenario. Singh and Sharma (2015) have observed that to make the supply chain competitive, organizations need to make their processes energy efficient and sustainable. Green supply chain strategies have become the backbone of many business organizations in today's environment conscious scenario. From the literature and according to other findings there is ample evidence to prove that there is a positive impact on business competitiveness by adopting green supply chain management.

Objective 4: To show that green supply chain management will promote cost efficiency and value enhancement simultaneously, enabling an organization to gain a sustainable competitive advantage.

To show that green supply chain management will promote cost efficiency and value enhancement simultaneously in an organization to help it achieve a sustainable competitive advantage, the researchers used simple linear regression. Researchers calculated the mean value of total competitive advantage by summing up the cost-benefit and the customer value enhancement. The results are shown in Table 19.

According to Martin Christopher (2011), to gain superior customer value at less cost there should be both cost-benefit and customer value enhancement. According to other research findings and Martin Christopher's insight, it seems entirely plausible that to gain a superior competitive advantage the simultaneous impact of cost-benefit and customer value enhancement should be felt by the organization.

Table 19. Regression Analysis

		R^2
CB = β0 + β1 GSCM+Ɛ	CB = -1.065 + 1.316GSCM+Ɛ	0.674
CVE = β2 + β3 GSCM+Ɛ	CVE = 1.661 + 0.624GSCM+Ɛ	0.507
CB X CVE = β4 + β5 GSCM+Ɛ	CB X CVE= 0.298 + 0.970GSCM+Ɛ	0.775

Source: SPSS output from field survey.

SOLUTIONS AND RECOMMENDATIONS

This research provides a number of potentially valuable ideas for managers. According to the research findings a high correlation exists between green supply chain management and cost-benefit rather than value enhancement; there is also a strong relationship between green supply chain management and combined competitive advantage elements, which are more effective than single elements. The impact of green supply chain management on cost-benefit also gets a high degree of value rather than its impact on customer value enhancement. The combined effect of cost-benefit and customer value enhancement on an organization's performance is very much higher than when these two single elements operate alone. Therefore, Sri Lankan Business organizations can learn some useful lessons by adopting and exploring some of these green practices.

According to the research findings organizations can gain a competitive advantage by introducing cost-benefit practices into the firm. It is better to focus more on and adopt cost-benefit approaches. Reducing energy-related costs can pay considerable dividends to many business organizations. In manufacturing organizations, high energy and water costs can prove to be a major drawback. Focusing on conservation, recycling and alternative energy sources can reduce these expenses. Switching to energy-efficient lighting and adjusting lighting levels in accordance with organization's production schedule will reduce the long-term electrical costs. Regular equipment inspections will also prove beneficial. Changing the packaging methods in accordance with green practices for products and supplies can contribute to cost reductions and free up space in the organization's premises. Solar and wind energy can be used along with energy-efficient equipment and machinery as that will greatly reduce monthly utility bills. Implementing strategies such as recycling and going paperless will also save on supply costs. Sustainability can improve the organization bottom-line.

At the same time, green practices can make the company's products more marketable. Consumers are now more conscious of the environment, and making improvements in this area will enhance the organization's reputation. If a supplier highlights the company's green initiatives to the public that will help the company to attract a whole new base of customers, resulting in increased sales. This is important to manufacturers seeking government contracts in which green manufacturing standards are often a factor. Technology and social media have enabled buyers to easily (and publicly) endorse or criticize companies for their green practices, or lack thereof. There is scope for attracting new customers by these means and thereby increasing the sales. As a result of that it may be possible to gain an edge over competitors.

Through greening of the supply chain management it may be possible to obtain a variety of tax credits and rebates at both the federal and state level (maybe in US but not in SL) by manufacturers who proactively implement sustainability improvements. It may lead to further cost-benefit if companies expand their green practices and become more environment-friendly.

Sustainability improvements are a collaborative effort. When employees work together to identify and implement green and sustainable initiatives, it fosters a culture of teamwork and continuous improvement. Employees work harder when they are absorbed in the work and have a sense of pride in their company. By internally communicating the importance of changes and the impact they will have on the business and environment, manufacturers will positively influence their corporate culture. It is necessary to inculcate in employees the importance of practicing sustainable methods to strengthen the economy of the country. In addition to raising the company's profitability, positive actions can make other real differences. By implementing progressive changes, companies will leave a smaller carbon footprint and reduce the number of toxins released into the environment. Future generations will ultimately benefit from the improved air and water quality, fewer landfills and greater reliance on renewable energy sources.

Further, the research findings demonstrate that there is a comparatively weak relationship between green supply chain management and customer value enhancements in Sri Lanka. As managers see it, it would be better to concentrate on customer value enhancement because organizations that improve the product quality can expect to get better customer responsiveness. By identifying the customers' needs and their perception regarding eco-friendly products, organizations can change their supply chain management practices as required.

Besides all that, the combined effect of cost-benefit and customer value enhancement is a critical success factor that would help to gain a competitive advantage. Organizations have to be concerned about both cost-benefit and customer value enhancement simultaneously when engaging in green supply chain management.

FUTURE RESEARCH DIRECTIONS

GSCM continues to be a significant research schema among researchers. However, it is still limited to studies that investigate GSCM adoption and implementation in developing countries. Therefore, the focus of this research will be on ISO 14001 certified firms in Sri Lanka, which is a typical developing country, as that will help to study about GSCM in greater depth. ISO 14001 certified firms will be the main subjects because they are expected to be the first to adopt GSCM practices. This assumption is supported by the studies of Darnall *et al*. and Zhu *et al*. (2004).

Hence, future research might help us to understand green supply chain management and competitive advantage relationships better by using mediation, moderation or non-linear relationships. As this thesis focused primarily on the role of competitive advantage, cost-benefit, and customer value enhancement in GSCM adoption, numerous other factors were left out, such as regulation, competitors, suppliers, and employees, which were not analyzed. Therefore, further effort should be put into examining the relationship between these presently excluded potential drivers and GSCM practices. Although there are earlier studies that identified the drivers of GSCM practices (e.g. Zhu & Sarkis, 2006; Lee, 2008; Walker *et al*., 2008; Thun & Müller, 2010), there is a need for further concept building on the connection between competitive strategy and GSCM strategies and its impact on competitive advantage.

Future research should resort to a multiple approach for obtaining data. Depending only on survey respondents to contribute data on what they imagine to be intra/ inter-business variables may cause some inaccuracies, and more than the usual amount of random error (Koufteros, 1995).

Future research can test the hypothesized relationships among countries. Thus, various SCM practices for attaining supply chain responsiveness in different countries can be compared, and country-specific SCM issues can be identified.

Future research can also survey SCM problems at the supply chain level by considering a complete supply chain. Furthermore, it will be interesting to study the effect of environmental factors and electronic commerce on supply chain responsiveness as well.

CONCLUSION

Green supply chain management is an emerging need in the current global business scenario. There are many pieces of research done on green supply chain management and competitive advantage. However, there have been contradictory findings about the cost-benefit element's capacity to deliver any competitive advantage from green supply chain management. There are researchers who express both positive and negative views on the green supply chain management's capacity to confer a competitive advantage to an organization. Therefore, it is clear that there is an empirical and knowledge gap in this research area. Green supply chain management researches were not popular in developing countries in the past and the elements that were checked for their ability to boost competitive advantage differed. The current research identified the impact of the green supply chain management on competitive advantage in terms of cost-benefit, customer value enhancement, and combined effect. Rather than identifying the impact the researchers identified the existing green supply chain management practices and the relationship between green supply chain management and competitive advantage.

This study used descriptive quantitative design. The population comprised organizations that were practicing green supply chain management in Sri Lanka and the sample size was 30 organizations. Sample technique was convenience sampling method. Data were gathered from primary as well as secondary sources of information, with primary data being gathered by means of a survey questionnaire.

According to the research findings, the relationship between green supply chain management and competitive advantage in Sri Lankan business organizations is a positive relationship. The most effective relationship was by combined effect and cost-benefit element. Also, the impact was higher by combining element effect, cost-benefit and customer value enhancement effect. This research helps to identify the prevailing green supply chain management practices in Sri Lankan business organizations.

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Chapter 5
Meta-Heuristic Approaches for Supply Chain Management

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ABSTRACT

Supply chain management (SCM) is essentially a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time in order to minimize system-wide costs or maximize profits while satisfying service level requirements. To solve complex problems in SCM and to obtain optimization, various meta-heuristics algorithms can be used. Thus, this chapter discusses the background of meta-heuristics algorithms. The related work and future research direction for using meta-heuristics approaches for supply chain management are addressed in this chapter.

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INTRODUCTION

Supply Chain Management (SCM) is the task of integrating organizational units along a Supply Chain (SC) and coordinating materials, information and financial flows in order to fulfil customer demands with the aim of improving competitiveness of the SC as a whole. (Stadtler 2005). A SC is defined as a system of services that delivers raw materials and these materials have become intermediate and final products, and have been dispersed among the customers (Simchi-Levi et al 2000). SC consist of suppliers, manufacturing sites, distribution centers, retailers and customers, and consists of two processes that are highly integrated with each other, such as production planning and inventory control process that deal with production, storage and relationship between them, and logistics and distribution process that how to transportation of products to customers and identifies how they are recycled.

Integration of activities, cooperation, coordination and information sharing throughout the entire supply chain, from suppliers to customers is a challenging task. Hence there is the necessity of refined Decision Support Systems (DSS) based on powerful mathematical models and solution techniques. There are improvements in the area of meta heuristics that can provide an effective response to complex problems in SCM. Meta heuristics have many necessary features to be an excellent method to solve very complex SCM problems: in general they are simple, easy to implement, robust and have been proven highly effective to solve hard problems. Even in their most simpler.

Section 2 introduces the background of various meta heuristic algorithms for SCM. Section 3 discusses the challenges involved in SCM, Section 4 discusses the related work based on SCM. Section 5 explains the future research directions and Section 6 concludes the chapter.

BACKGROUND

Furthermost of real-world, SC problems are complex due to high number of indices which increase the dimension of the problem and it may lead to inefficiency of routine solution approaches (Fahimnia et al. 2013). Increase in the size of problem and the exponential growth in complexity makes the model to be NP-hard (Park et al. 2007; Jolai et al. 2011). Meta heuristic solution methodologies can be applied for the above problem. Two classifications of meta heuristic algorithms are as follows: (1) population approaches, such as ant colony optimization, the genetic algorithm, particle swarm optimization, and bee colony algorithm; and (2) trajectory approaches, such as the tabu search, and simulated annealing.

Ant Colony Optimization (ACO) Algorithm

The Artificial Bee Colony (ABC) algorithm is a swarm intelligence algorithm stimulated by the foraging behavior of bees and it was introduced by Karaboga. In ABC algorithm, the colony comprises of three types of bees such as employed bees, onlooker bees and scout bees (George & Binu 2018). In this algorithm, each food source represents solutions of the problem and nectar amount represents fitness of the solution (yadhav et al 2017). Onlooker bees who are associated with a food source make decisions based on the dancing of employed bees. Scout bees are responsible for searching food source. Onlookers and scouts are also called unemployed bees. In the initialization phase scout bees will search and find the food sources. Thereafter, the food sources are exploited by employed bees and onlooker bees. This manipulation will cause the food source to become exhausted. Whenever the food is exhausted, the employed bees that are associated with that particular food source will become scout bees and search for food source. Number of food sources and number of employed bees will be same since each bee can produce one and only one solution.

Genetic Algorithm (GA)

Genetic algorithms have been originated on the principles of natural evolution (Toroudi 2017). This evolutionary algorithm has progressed over the generations and the perseverance of development is the fitness of individuals. The basic principles of genetic algorithms were presented by John Holland in 1975. Later this method was developed by scientists such as Goldberg and Davis. Two main mechanisms that are based on Darwin's theory in the evolution of living organisms are selection and recreation. Selection ensures that people with higher fitness, have higher recreation function and Survival. Recreation involves permission of composition, procreation, and diversity of parent's features to produce offspring with new features.

Particle Swarm Optimization (PSO)

In 1995, Kennedy and Eberhartin, inspired by the choreography of a bird flock, first proposed the Particle Swarm Optimization (PSO). (Radhakrishnan 2013). PSO is one of the meta-heuristic algorithms that have been applied in many areas and is a suitable approach for several optimization problems (Iwan et al 2014). It is a population-based algorithm that exploits individuals in the population towards the completion of the search area. In PSO, a population is called a swarm, and the individuals referred to the particle. Each particle moves with the speed of adaptation of the search area and stored as the best position ever achieved.

Pareto Ant Colony Optimisation

In the Ant Colony Optimisation (ACO) meta heuristic, colonies of artificial ants collaborate to find solutions to difficult discrete optimisation problem (Moncayo-Martínez & Zhang, 2007). Real ants have the capacity of smelling and depositing a chemical substance called pheromones (τ) that permit them to communicate each other. Ants move randomly when they leave the nest but when ants find a pheromone trail, they decide whether or not to follow it. If they decide to do so, they deposit their own pheromones over the trail. The probability that an ant selects one path over other is based on the quantity of τ deposited over the path. With time, the amount of τ on a path evaporates. Before the colony finds the shortest path between the nest and the food, they use all the potential paths in equal number, depositing pheromones as they travel but the ant that takes the shorter path will return to the nest first with food. The shorter path will have the most τ because the path has "fresh" pheromone and has not yet evaporated and will be more attractive to those ants that return to the food source. In artificial ants the ants travel in a network in which the τ are deposited over either the vertices or edges. The nest is represented by an initial condition and the food by a terminal condition. The ants select a vertex or a node for stepping forward based on a probabilistic decision rule that is function of the quantity of τ deposited over the node or edge. The way in which A deposits and smells τ is by means of a Pheromone Matrix (PM). The problem is represented by a set of constraints that every time an ant selects a vertex or edge, it has to evaluate the set of constraints.

Simulated Annealing

Simulated Annealing (SA) is adapted from metal annealing (Babaveisi et al, 2017). In this process, the metal is heated so that its particle can move freely. As the temperature decreases, the movement will be more limited. Solutions in problems are defined as particles in the metal.

CHALLENGES

Some of the key issues in SCM, includes (Lourenço, 2014):

- Supply-chain integration.
- E-commerce and e-logistics
- Material handling and order picking
- Customer service

- Logistics of production and operations
- Warehouse management and distribution strategies.
- Inventory management.
- Information systems and DSS
- Reverse and green logistics
- Facility location and network design
- Transportation and vehicle routing
- Product design

One of the main issue is discussed as follows: Computer and information technology has been utilized to support logistics for many years. Information Technology (IT) is seen as the key factor that will affect the growth and development of logistics and it is the most important factor in an integrated supply chain, also playing an important role in the executive decision-making process. More sophisticated applications of IT such as DSS based on expert systems, simulation and meta heuristics systems will be applied directly to support decision making on SCM. A DSS incorporates information from the organization's database into an analytical framework with the objective of easing and improving the decision making. The author discussed that meta heuristics, when incorporated to a DSS for SCM, can contribute significantly to the decision process, especially taking into consideration the increased Complexity of the logistics problems. DSS based on meta heuristics are not currently widespread, but it appears to be growing as a potential technique to solve hard problems as the one related with SCM.

RELATED WORK

Various solution methods ranging from exact linear solvers to meta-heuristic and heuristic algorithms have been developed to solve supply chain optimization models (Fahimnia et al, 2018). To achieve quality solutions in a relatively reasonable length of time has remained a challenge for both academics and practitioners. The use of linear solvers such as CPLEX has been quite popular to tackle small and medium-size problems that can be presented in a linear form. Meta heuristic and heuristic algorithms have been developed to explore solutions to large and/or nonlinear optimization problem. Heuristic methods are typically designed based on problem structure and mathematical particularities. They are rather problem dependent and a heuristic method may not serve the purpose to solve a range of optimization problems. Meta-heuristics, are general-purpose algorithms that can be applied to solve a range of optimization problems.

Osman et al 2014 has introduced Dynamic Virtual Bats Algorithm (DVBA), which is tested on several benchmark functions for global optimization and DVBA has been applied to minimize the supply chain cost with other well-known algorithms, PSO, Bat Algorithm (BA), GA and TS. He discussed that optimization of supply chain is considered as a real challenge by researchers because of its complexity such as big number of parameters to be controlled and their distributions, interconnections between parameters and dynamism. ArnabKole et al 2014 applied ACO algorithm to solve incapacitated Facility Location Problem. This problem had also been solved using another meta-heuristic method PSO technique.

Zhao & lo 2011 have discussed optimal design of Agri-food Supply Chain Network (ASCN) which is critical to reduce the sum of production cost and transportation cost. A Mixed Integer Programming (MIP) model is presented to handle facility location and production capacity selection as well as choice of transportation mode for ASCN design problem. Due to the complexity of the design problem for the multi-echelon and multi-product ASCN, an improved PSO approach is proposed. For binary decision variables, local search within the neighborhood of best solution is embedded into PSO to enhance the exportability.

SA and GA have been undoubtedly amongst the most popular meta-heuristics for solving large-scale and/or nonlinear optimization problems.GA has been successfully employed in different supply chain problems, such as production and transportation planning, vendor-managed inventory problem, lot-sizing and delivery scheduling and supply chain design and planning. The application of SA has also been investigated in a broad range of production and operations management problems such as production sequencing facility location, location and routing and distribution planning.

Sadeghi et al. (2014) presented a multi-objective combinatorial optimization model of a supply chain problem including one-vendor multi-retailers considering a vendor managed inventory approach. Their proposed model included two objectives, minimization of inventory cost as the first objective and maximization of the system reliability of the machines that produce the goods as the second. Since the developed model was NP-hard, they applied two multi-objective genetic algorithms, namely, NSGA-II and NRGA, to find Pareto fronts.

FUTURE RESEARCH DIRECTIONS

(Govindan et al 2017) have discussed SCND is one of the most crucial planning problems in SCM. Few studies applied meta-heuristics approaches. Somehow that meta-heuristics cannot guarantee the optimal solution for an optimization problem. Therefore, presenting solution algorithms, which are based on the combination of exact methods with heuristics or meta-heuristics is another future area of research.

(Marchi & Zanoni 2017) have discussed that, energy efficiency has acquired greater relevance representing a strategic key resource for economic and social development because it provides multiple benefits to different stakeholders. From the industrial user's perspective, energy efficiency can result in great cost savings, improved competitiveness, profitability and quality, a better working environmental, etc. In spite of these multiple benefits, most firms still face many difficulties and, in some cases, hostility when trying to implement energy efficiency plans. The most dominant of these barriers, especially for SMEs, are access to capital and lack of awareness. SCM is one of the main ways to overcome those barriers; it can also support the implementation of energy efficiency measures for companies with a lower competitive positioning in the marketplace. From the analyses presented by the authors, it is possible to observe that very few works have integrated energy efficiency concerns into the study of SCM using both qualitative and quantitative approaches. The publications that propose a qualitative approach have mainly focused on showing the relevance that energy issues have in affecting supply chain performance, the optimal decision-making process, and the opportunity to improve the energy performances that results from collaborative efforts of members of a company's supply chain. The quantitative models provided in most of the reviewed studies mainly aim to introduce the additional costs associated with the energy flow in the total supply chain cost, and only a few studies have considered energy performance as an objective function or as a decision-making variable. The analyses show how energy efficiency achieved through appropriate supply chain design and management is still poorly investigated and has many opportunities to develop from the practice and research point of view.

CONCLUSION

Today's competitive market makes the supply chain management more important. Nowadays, to survive in a highly competitive market place, companies have to reduce supply chain risk, improve the distribution methods, optimize inventory levels and improve customer service and customer satisfaction. (Afrouzy et al 2018). SC strategy is vital for success of any business organization (Sathish Kumar et al 2018). Most real-world optimization problems belong to the class of NP-hard problems and to solve NP-hard problems, there are not provably efficient algorithms. Exact methods cannot solve this class of problems in normal and reasonable time. To optimize this class of problems meta- heuristic algorithms are suitable tools. Thus this chapter has discussed the various meta heuristics algorithms to implement in SCM.

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Chapter 6
Multi-Objective Decision Analysis in Strategic Supply Chain Design

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ABSTRACT

This chapter introduces the impact of competitive strategy on strategic supply chain network design decisions. The aim of increasing competitive advantage forces firms to deal with multiple conflicting objectives. Since supply chains are affiliate networks including multiple parties, accomplishing a solitary objective corresponds to an inadequate effort to maintain the sustainability of supply chain. The overall integrity and sustainability of the supply chain can be provided by satisfying the expectations of each parties. The loyalty in the supply chain is achieved by offering distinguished service among suppliers and customers rather than delivering almost same services. This can only be achieved through network design models by taking into account multiple conflicting objectives. The firm's competitive strategy defines a particular set of objectives to achieve specific goals on these performance attributes. This chapter examines the main problem domains in SC design, strategic performance measures, and recent literature on single/multiple objective models.

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1. INTRODUCTION

The essence of formulating competitive strategy is to define the position in the industry to preserve market share and challenge the other competitors in the market to increase firm's favor. The competitive strategy determines the building blocks of the supply chain network design. A successful supply chain design can only be provided by the resolution of infrastructure through well-defined competitive strategy. It requires strategic decision making that outlines the main characteristics and the main capabilities of the supply chain Supply chain design consists of decisions that influence the investment patterns made by the firm across its various supply chains (Melachrinoudis & Min, 2000).

Managing supply chains (SCs) effectively is a complex and challenging task due to current business trends of expanding product variety, short product life cycle, increased outsourcing, globalization of businesses, and continuous advances in information technology (Lee, 2002). Currently, the traditional performance indicators are lack of creating distinguished competitive advantage among many suppliers since they create approximately equivalent services in terms of conventional criteria (ie. cost). Therefore, a tailored approach should be taken up seriously while defining the competitive strategy rather than generic definition.

The main goal of a SC is to maximize the value created by fulfilling stakeholders' prospects. Stakeholders are generally classified into two groups: internal and external. Internal stakeholders are the staff and shareholders that aim to make higher revenue. Simply, they create value for use of customers through the operations, as such designing, producing, packaging and shipping the products. External stakeholders are generally customers, suppliers, communities, contractors and government. Suppliers are critical stakeholders owing to their role in the supply chain. The positive and innovative contribution of supplier to the supply chain yields superior results in terms of increasing customer satisfaction and delivered quality. Additionally, efficient collaboration with suppliers in terms of shared strategy and goals builds inter-business loyalty and conclusively contributes increasing the loyalty of customers. Since the ultimate goal of supply chain is to meet customers' expectations, they are said to be the most critical stakeholder.

Supply chains aim to maximize the delivered value among stakeholders by managing upstream and downstream flow of information, service and products. Considering the comprehensive scale of supply chain, formulation of a unique model, including every supply chain processes and real-world aspects, is almost impossible. The levels in supply chain, interrelationships, uncertainty on problem parameters and variety of objectives makes the problem more challenging. Supply chain modelling problem focuses on multiple conflicting objectives, since the ultimate goal is to find a compromise solution to satisfy the requests of various stakeholders.

The essence of this chapter is to reveal the design requirements of a supply chain while effects of internally-focused and customer-focused objectives of a supply chain are considered concurrently. A holistic design framework is suggested in order to maximize the aggregate value generated by fulfilling internal and external stakeholders' expectations.

This chapter summarizes the main objectives and key performance attributes in supply chain design problem. Since the problem mainly includes more than one objective, the studies on finding compromise solutions in supply chain design are investigated. Section 2 provides the background on supply chain performance attributes and relevant literature. In section 3, three supply chain problem domains are investigated by giving fundamental formulations with single objectives. The literature review on multiple objective supply chain design is represented in Section 4. In the final section, the importance of multiple objective supply chain problem is implied. Furthermore, the future research suggestions in the literature are summarized in this section.

2. BACKGROUND

The primary purpose of the supply chain is to provide value to customers by delivering goods and services and improve customer loyalty. The way of enhancing loyalty is at least to sustain the difference between the perceived total value and perceived total cost by customer. Therefore, a set of goals is defined to assess performance of supply chain operations in terms of the net perceived value to customers. Although the most frequent objective is cost minimization in the literature, it is clear that a large number of attributes should be taken into account when customer expectations are considered simultaneously.

The Association for Supply Chain Management, APICS (n.d.), defined over 250 performance measures that are categorized in five performance attributes: reliability, responsiveness, agility, costs and asset management efficiency. The first three attributes are customer-focused; the remaining attributes are internally focused (APICS, n.d.). The firms are aligned through competitive strategy by determining specific goals for these performance attributes. These performance attributes are employed in formulating complicated objectives and in evaluating the efficiency of supply chain design.

The competitive strategy of a firm has a significant influence on network design decisions within the supply chain (Chopra & Meindl, 2007). If the competitive strategy is mainly focused on reliability and responsiveness attributes, which may be on-time delivery or the exact quantity, the firm experience a higher cost while locating its facilities. If the competitive strategy is mainly focused on cost attributes, the firm decides on low-cost locations for its facilities and searches for low-cost transportation options.

For an effective supply chain design, well-defined competitive strategy should be interpreted to formulate appropriate objectives and identified in a breakdown (ie. tree) structure including means-ends objectives. A conceptual objectives hierarchy model can be employed to visualize the relationship between strategies at one end and objectives at the other end.

Beamon (1998) summarized the available literature on supply chain performance measures, which are categorized as qualitative or quantitative. Qualitative performance measures incorporate the expectations from product as well as the expectations from the supplementary processes. Since quantitative performance measures can be represented numerically, they are typically involved in supply chain network model as objectives.

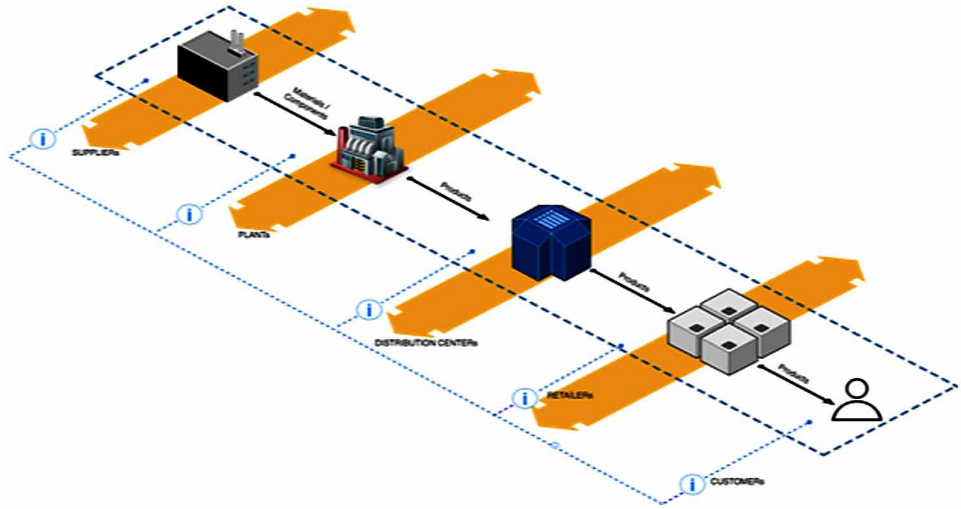
3. SINGLE OBJECTIVE SUPPLY CHAIN NETWORK DESIGN PROBLEMS

A supply chain is a network of organizations that aims to deliver value to customer by managing upstream and downstream flow of information, service and products. Figure 1 illustrates a generic view of supply chain network. The design of a supply chain primarily focuses on satisfying the customer expectations. These expectations stimulate supply chain network design on achieving specific levels at both qualitative and quantitative performance measures. The specification and prioritization of quantitative performance measures generally results with determining the main objective.

Therefore, the objective of the supply chain design problem may be the maximizing responsiveness, minimizing of total supply chain cost, minimizing the risk, etc. The most common objective, total cost minimization, generally includes inventory, setup and transportation costs. Moreover, cost-based objectives are extended to maximizing profit, maximizing revenue or maximizing return on investment in the literature.

Supply chain network design is a strategic level problem that determines the number, the capacity and the location of facilities, and the flow of goods among these facilities through a supply chain network. The primary objective of strategic optimization models is to determine the most cost-effective location of facilities, flow of goods throughout the supply chain, and assignment of customers to distribution centers (Sabri & Beamon, 2000). Definitely, design of the network has the most significant impact on the supply chain performance. It determines the total required investment under a set of constraints to achieve a set of performance measure. Memorizing the competitive strategy, the supply chain network should be designed

Figure 1.



regarding superiority in some performance attributes, whereas achieving acceptable levels for the remaining attributes.

For an extensive literature review on supply chain network design, we refer Melo et al. (2005). The study examines approximately 120 articles, that are published between 1999-2009, and identify the basic features of the articles to support decision-making in strategic supply chain planning. The articles are investigated for supply chain structure featuring the number of commodities, the nature of the planning horizon, the number of echelons and the type of data. Moreover, the methods to solve these problems are also examined. Supply chain network design literature can be classified into three groups: facility location problems, capacity allocation problems and network design. As the assumptions and data structure change in supply chain network, these problems provide an exhaustive list of applications and varying problem areas. In this section, we present brief definitions and corresponding literature reviews for these problems.

Facility Location Problems

Facility location problem (FLP) involves a set of customers to serve, a set of facilities to operate (producing, storing, distributing etc.), fixed costs associated to invest on facilities (open/not), and variable costs related to operations. The main purpose of the problem is to define the subset of facilities that should be opened and the assignment of each opened facility to each demand point where the sum of total fixed cost and total variable cost is minimized.

The primary linear programming formulation of FLP can be defined by a mathematical model for static deterministic uncapacitated FLP.

$$\text{minimize } \sum_i f_i Y_i + \sum_i \sum_j c_{ij} X_{ij} \tag{1}$$

$$\text{st. } \sum_i X_{ij} = 1 \forall j \in J \tag{2}$$

$$X_{ij} \leq Y_i \forall j \in J, \forall i \in I \tag{3}$$

$$X_{ij} \geq 0 \forall j \in J, \forall i \in I \tag{4}$$

$$Y_i \in \{0,1\} \forall i \in I \tag{5}$$

where $i \in I$ is the set of candidate locations to set up a facility, $j \in J$ is the set of customer, is the fixed cost of establishing a facility at location i, c_{ij} is the total cost of supplying demand of customer j by the facility located at i. The uncapacitated FLP problem has two decision variables: X_{ij} denotes the fraction of the demand of customer j supplied from the facility located at i and Y_i is a binary variable assuming a value of 1, if a facility is located at i and 0 otherwise. The objective function (1) represents minimizing the total cost, whereas the constraint (2) guaranties that the demand of each customer to be fulfilled and constraint (3) customers can only be supplied from opened facilities.

The uncapacitated FLP formulation is generally extended to more complex formulations in order to assess the impact of various conditions such as; multiple products, capacity limitation, hierarchical structure, dynamic environment and etc. These extensions generate a wide-range categorization in FLP literature. Facility location problems may be categorized as single FLP and multiple FLP. Single facility location problem deals with deciding the location of a single facility that minimizes the total distance between the facility and the demand points, where multiple FLP determines the set of optimal locations to meet demands. If the number of possible locations is finite and a list for possible locations is given, then the problem becomes a discrete FLP. If the possible locations are not restricted and the facilities can be located at any place in a given region, then the FLP is said to be continuous. Another categorization for FLPs is whether the problem is capacitated or uncapacitated. If there is no limitation for the capacity of new facility, then the FLP becomes uncapacitated. The Lastly, FLP problems are categorized into single level and multiple level FLPs. Multi-level FLP is also called hierarchical facility location problems, where systems involving different types of interacting facilities that provide services to a set of customers (Ortiz-Astorquiza et al., 2017). We refer reader for the recent literature review of Ortiz-Astorquiza et al. (2017).

Capacity Allocation Problems

In the long term, strategic resource allocation in supply chain design arises the problem of determining capacity requirements of suppliers, plants and supplementary facilities as well as the allocation of these capacities to each product (Li et al., 2009). Fulfilling the customer demand is directly associated with the limited capacities for supplies, production and distribution. The main purpose of the optimization at the operational level is to determine the safety stock for each product at each location, the size and frequency of the product batches that are replenished or assembled, the replenishment transport and production lead times, and the customer service levels (Ortiz-Astorquiza et al., 2017).

When the competitive strategy of a firm is mainly based on flexibility/ responsiveness attributes, the capacity allocation problem becomes more critical. Many researchers have contributed to solve capacity allocation problem, but the majority of the published articles on capacity allocation have focused on the manufacturing stage rather than the entire supply chain network (Li et al., 2009). Martínez-Costa et al. (2014) presents a detailed review on the strategic capacity for manufacturing level and summarizes the problems of determination of the capacity size (expansion, replacement, reduction) and allocation of capacities to facilities. The problem becomes very complex when each level of supply chain is considered.

The capacity planning problem is not adequately visited in the literature when a supply chain design is considered in strategic level. The capacity limitation is generally handled with capacitated facility location problem. In the literature, the multi-level capacity allocation problem is investigated for maximizing the total profit (Li et al., 2009), minimizing the total cost (Pirkul & Jayaraman, 1998). Capacity allocation problems handle mostly flexibility consideration in supply chain design and evaluate it by regarding the issues on uncertainty in capacity and demand.

An important study in the literature is done by Melo et al. (2005) which proposes a framework to capture many aspects of network design problem. The study investigates how supply chain network design problem can be formulated considering dynamic planning horizon, multi-level network structure, external supply of materials, inventory opportunities for goods, distribution of commodities, facility configuration, availability of capital for investments, and storage limitations. Additionally, they examine the gradual relocation of facilities over the planning horizon as well as fluctuating demands, capacity expansion/reduction scenarios and modular capacity shifts.

Network Design

Network design problem involves only the design decisions that are involved through activation of edges among facilities and the allocation of customers is implicitly given by the opening of the corresponding edge (Ortiz0Atorquiza et al., 2017). These problems are categorized according to number of levels involved in the supply chain. Mathematical models for solving the network design problems are based on a generic model which is called minimum cost network flow problem.

The primary network design problem is the minimum cost network flow problem (MCNFP) in graph theory, as given by Bazaara et al. (1990) as in Eq.1-3. A network is represented as a graph $G\left(\mathcal{N},\mathcal{A}\right)$ where $\mathcal{N}$ denotes the set of nodes and $\mathcal{A}$ is the set of directed or undirected arcs.

$$\text{minimize } \sum_{i=1}^{m}\sum_{j=1}^{m} c_{ij} X_{ij} \tag{6}$$

$$\sum_{j=1}^{m} X_{ij} - \sum_{k=1}^{m} X_{ki} = b_i, i = 1,\ldots,m. \tag{7}$$

$$X_{ij} \geq 0 i, j = 1,\ldots,m. \tag{8}$$

The objective is generally minimizing the total cost associated with the network, which is generally defined as the sum of individual cost contribution of each arc, as in equation 6. Constraint 6 is the flow conservation equation that defines the net flow from node i, which is defined as the difference between the total flow out and the total flow into node i, is equal to b_i.

In the operations research literature, a variety of algorithms and data structures have been developed for solving MCNFP. A large number of different polynomial time algorithms for MCNFP exist (Sifelaras, 2013). The classical network simplex algorithm remains the best choice for solving MCNFP. Another efficient method for solving MCNFP is out-of-kilter algorithm.

Two special variation of MCNFP are the maximal flow and shortest path problems. In maximum flow problems, each arc has both a lower bound and an upper bound for the flow of entities and aims to maximize the total flow on the network from an initial node to a terminal node. In shortest path problems, the aim is to find least costly path from an initial node to a terminal node. As the definition of the two problem implies, a shortest path problem can be seen as a network flow problem if the network is set up in which a single unit of flow will be sent from the initial node to the terminal node at a minimal cost (Bazaara et al., 1990).

A strategic supply chain network design model considers an integrated, multi-product, multi-echelon and procurement–production–distribution system design problem in a flexible facility network configuration (Sabri & Beamon, 2000). So, it is a complex network of organizations and facilities which are settled in a widespread geographical area and requires synchronized a series of interrelated activities through the network (Govindan et al., 2017). In the literature, supply chain network model is generally formulated as a mixed integer linear programming model to minimize the total supply chain cost. However, the studies involving more specialized objectives are not less. Fattahi et al. (2015) presents a mathematical model to maximize the supply chain's net income of a multi-echelon and multi-product supply chain network over a multi-period horizon. They also include dynamic pricing and capacity planning in SC network design in which customer zones have price-sensitive demands.

The uncertainty on supply chain design is also studied in the literature. Regarding the major concentrations of studies, they can be grouped in two categories: Stochastic Models and Fuzzy Models (Govindan et al., 2017). Nickel et al. (2012) propose a multi-period multi-commodity and two-level stochastic supply chain network design problem. They have taken uncertainty into account by defining stochasticity on the demand and the interest rates. A set of scenarios is considered to describe uncertainty. The service level for each customer and the ROI of investments are evaluated and weighted in the objective function. The model determines which facilities that should be operating, the amount of loans to get and the flow of commodities through the network. Govindan et al. (2017) present a comprehensive review of studies on supply chain network design under uncertainty. They examined the literature especially on planning decisions, network structure, paradigms and existing optimization techniques for dealing with uncertainty in supply chain design.

Consequently, supply chain design problem does not only involve a forward flow of products and services among suppliers, production facilities, warehouses, distribution centers and customers, but also includes the reverse flow of the goods and the information among additional facilities (ie. collection centers, recovery facilities). Managing supply chain operations has already been a very difficult task even for a single objective, it is a fundamental requirement to consider the problem with more than one objective regarding its definition. Multi-objective supply chain modelling includes the expectations of each stakeholder and contributes to the sustainability of the supply chain.

4. MULTIPLE OBJECTIVE SUPPLY CHAIN NETWORK DESIGN PROBLEMS

In supply chain modeling, the performance measures are expressed as functions of one or more decision variables (Beamon, 1998). The supply chain modelling requires optimization of the levels of performed KPIs. As summarized in Section 2, every supply chain design focuses on specific levels of performance measures. We examine the decision variables used in strategic level supply chain network design problems as:

- **The Number of Facilities:** This includes the determination the number of distribution centers, warehouses and plants in the supply chain.
- **The Number of Levels in a Supply Chain:** This involves either increasing or decreasing the chain's level of vertical integration by combining (or eliminating) stages or separating (or adding) stages, respectively (Beamon, 1998).
- **The Description of Facilities:** After the number of facilities determined, the locations, the roles, the qualifications and associated capacities of each facility should be evaluated.
- **The Size of Product Variety:** Multi-commodity supply chains are generally more complex than single-commodity supply chains. Most of supply chains in the real world includes more than one product. The variety of the products served by supply chain effects the supply chain design problem.
- **The Assignments in Supply Chain Network:** The network structure of supply chain is built by assigning the plants to products, assigning warehouses to plants, assigning distribution centers to retailers (customers).

In the tactical stage, the subdivisions of strategic decisions are considered in detail, such as production decisions, scheduling decisions, routing decisions, inventory decisions.

The literature review (Melo et al., 2009) states that the most frequently used objective function to measure supply chain performance is cost minimization objective. Moreover, the majority of the articles surveyed is to determine the network configuration with minimum cost rather than maximization of profit. Just %10 of surveyed articles deals with the conflicting objectives (Melo et al., 2009).

Supply chain design problem involves several conflicting objectives. Supply chain network design is aimed to satisfy the demands of its customers by setting appropriate goals for the performance measures. Memorizing the reliability, responsiveness and agility performance measures are focused on customer satisfaction, these objectives mainly increase the total cost of supply chain and create fluctuations on asset efficiency. Generally speaking, customer-focused objectives and internally focused objectives conflict each other. Regarding the sustainability of a system, in section 2, the main goal of supply chain is defined as to maximize the value generated by satisfying the demands of both internal and external stakeholders. Therefore, both internally-focused and customer-focused objectives should be evaluated together, although they increase complexity and conflict in the problem. This section summarizes the recent literature on supply chain network design problem considering conflicting objectives.

Farahani et al. (2010) present an extensive survey including 730 papers on multi-criteria location problems and categorized them into three problems: bi-objective, multi-objective and multi-attribute problems. Additionally, they list several location-related (conflicting) objectives as such: minimizing the total setup cost, minimizing the longest distance from the existing facilities, minimizing the maximum time travelled, maximizing responsiveness and etc. In bi-objective models, transportation cost and distance are generally assessed with minisum and minimax objectives. They also examine the multi-attribute models for multi-criteria location problems with the techniques of compensatory methods and non-compensatory methods.

Melachrinoudis and Min (2000) formulate a multiple objective mixed integer programming model regarding three objectives: the maximization of total profit, the minimization of total access time, and the maximization of aggregated local incentives. The model is conducted for the design of multiple-period, multiple-level and single commodity supply chain network and applied to a real-life problem.

Sabri and Beamon (2000) develop an integrated multi-objective supply chain that is adopted to allow use of a performance measurement system including cost, customer service levels and flexibility. Customer service levels are evaluated in terms of the fill rate measure which corresponds to the percentage of orders immediately filled. They evaluate flexibility with two performance measure: volume flexibility and delivery flexibility. They measure the volume flexibility by a capacity slack and the delivery flexibility by a lead time slack.

Altıparmak et al. (2006) develop a new procedure based on genetic algorithms to find the set of Pareto-optimal solutions for multi-objective SC network design problem while considering three objectives: the minimization of total cost, the maximization of customer coverage (acceptable delivery time) and the maximization of capacity utilization.

Bilir et al. (2017) propose a two-level SC network design model that has three objectives: the maximization of the total profits, the maximization of the total amount of sales and the minimization of supply chain risks. They include an improved modelling on price- and service-dependent demands and risk management in the design phase of a supply chain network.

Govindan et al. (2017) develop an integrated optimization model in order to minimize the total cost, to maximize of supplier performance, and to minimize the transportation emissions for closed-loop supply chain network design. They formulate single-commodity, multi-period, fuzzy multi-objective and multi-level SC model and integrate the decision of supplier selection into supply chain design problem.

Strategic SC design problem involves determining the number and location of facilities, the variety of products, the assignments among facilities, their descriptions and capacities under several conflicting objectives. Regarding the ultimate goal of increasing the total benefit for every stakeholder, the achievement levels for each objective should be defined. Considering these objectives simultaneously makes the problem harder to solve. Therefore, multi-level optimization approach may be adopted to solve the strategic SC design problem by considering the problem in a hierarchy structure. The multi-level optimization approach determines a hierarchy for a series of sub-problems and solves the problem for corresponding constraints. These sub-problems may have single or multiple objectives. The multi-objective models can be either a preemptive models and weighted multi-objective models. This modular structure assists to solve such complex problems.

5. CONCLUSION AND FUTURE RESEARCH

Strategic supply chain design requires a well-defined competitive strategy to identify the resolution of organization through the network. Correspondingly, the optimization of supply chain networks plays a key role in determining the competitiveness of the whole SC (Bilir et al., 2017). Therefore, during the last two decades, an increasing number of studies have focused on the optimization of the overall SC network (Bilir et al., 2017). However, the number of studies including a single objective function is still higher than that of evaluating the conflicting objectives.

In this chapter, we define the goal of a supply chain as to maximize the value generated by fulfilling internal and external stakeholders' expectations. Hence, we investigated the objectives both internally-focused and customer-focused that increase complexity and conflict in the SC design problem. Besides, we emphasized the importance of compromise solutions for a sustainable design. This chapter presents a brief summary of studies in the field of supply chain network design. Especially, we focused on the effect of attributes on strategic SC network design.

Regarding the studies in the literature on SC network design, future research studies can be summarized in the following subjects:

- The interaction between the competitive strategy and supply chain design can be investigated. The depiction of a conceptual framework that defines the transfer of information and transformation of the information into processes will be notable.
- Specialized performance measures (unlike cost minimization, profit maximization) can be employed for designing SCs. Specific performance attributes on reliability, responsiveness, agility and asset management efficiency can be evaluated.
- New solution procedures for solving multiple-objective models can be investigated.
- Capacity allocation/expansion decisions can be examined in the SC design context.
- The effect of product variability on SC design is an also interesting problem.

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Chapter 7
A Case Study for Supply Chain Management Using System Dynamics

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ABSTRACT

System dynamics is an interdisciplinary problem-solving methodology that utilizes several significant thinking skills such as dynamic thinking and cause-and-effect thinking. System dynamics is a disciplined collaborative approach that could accelerate learning by combining a multifaceted perspective that provides insight into complex and interactive issues. System dynamics is designed to model, analyze, and improve socio-economic and administrative systems using a feedback perspective. Dynamic structured administrative problems are modeled by mathematical equations and using computer software. Dynamic constructions of model variables are obtained using computer simulations. In this chapter, a system dynamics model will be developed for supply chain management. The case study will be developed using VENSIM package program.

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INTRODUCTION

System dynamics approach was developed by Jay Forrester from MIT during 1950's to analyze especially the complex behavior in administration with computer simulation in social sciences. System dynamics is a form of systems approach as a methodology to understand the dynamic behavior of complex systems. The basis of system dynamics is to understand how system structures cause system behavior and system events (Sezen, 2009: 298).

Jay Forrester initially constructed his first dynamic model upon his meeting with the management of General Electric corporation. Big fluctuations in production, inventory, labor force and profitability were compelling GE management. Despite hard efforts of the management, these fluctuations were mostly associated with external factors. Especially, the fluctuations in the business were related to received orders. Forrester interacted with the management to observe the system operations in other departments. In the first model he developed, he observed that simulations were necessary since the system could not be monitored analytically. He demonstrated that the corporation could experience serious fluctuations due to management policies even when the demand is considered constant with the weekly simulation he ran. Later on, he designed the computer simulation for the same problem. In his later studies, Forrester demonstrated how the feedback control theory could be adapted for complex administration and human systems. He published his initial findings in an article in Harvard Business Review. Later on, he developed this study to write his famous work "Industrial Dynamics" (Lane and Sterman, 2011; Ramage and Shipp, 2009: 100-101).

SUPPLY CHAIN MANAGEMENT

The concept of supply chain management is relatively new. It was first articulated in a white paper produced by a consultancy firm-then called Booz, Allen and Hamilton-back in 1982. The focus of supply chain management is on co-operation and trust and the recognition that, properly managed, the 'whole can be greater than the sum of its parts'(Christopher, 2016).

Supply chain management can be defined as(Christopher, 2016):

The management of upstream and downstream relationships with suppliers and customers in order to deliver superior customer value at less cost to the supply chain as a whole.

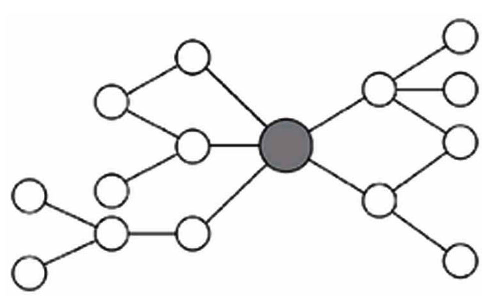
Another description of supply chain can be defined as (Christopher, 2016):

A network of connected and interdependent organizations mutually and co-operatively working together to control, manage and improve the flow of materials and information from suppliers to end users.

There is a basic pattern to the practice of supply chain management. Each supply chain has its own unique set of market demands and operating challenges and yet the issues remain essentially the same in every case. Companies in any supply chain must make decisions individually and collectively regarding their actions in five areas: Production, inventory, location, transportation and information (Hugos, 2018).

- **Production:** This activity includes the creation of master production schedules that take into account plant capacities, workload balancing, quality control, and equipment maintenance.
- **Inventory:** What inventory should be stocked at each stage in a supply chain? How much inventory should be held as raw materials, semi-finished, or finished goods?
- **Location:** Where should facilities for production and inventory storage be located? Where are the most cost-efficient locations for production for production and for storage of inventory? Should existing facilities be used or new ones built?
- **Transportation:** How should inventory be moved from one supply chain location to another?
- **Information:** How much data should be collected and how much information should be shared?

Figure 1. The supply chain network
(Resource: Christopher, 2016)



The focus of supply chain management is upon the management of relationships in order to achieve a more profitable outcome for all parties in the chain. This brings with it some significant challenges as there may be occasions when the narrow self-interest of one party has to be subsumed for the benefit of the chain as whole (Christopher, 2016).

SYSTEM DYNAMICS

System dynamics deals with how things change over time. Almost all are interested in how the past formed the present moment and how today's actions determine the future (Forrester, 1995: 16).

The concept of dynamics indicates change over time. If something is dynamic, it changes constantly. Therefore, a dynamic system is a system in which there are interactions that promote change over time. System dynamics approach is a method used to understand how the system changes over time. The elements and variables that constitute a system that changes in time are expressed as the system behavior. The aim is to understand the basic behavior system of the variables, to discover the factors that cause this mode of behavior and to improve the system behavior. Thus, it could be argued that system dynamics is a method to explain how the systems change with time. In dynamic systems, variables influence each other simultaneously (Barlas, 2005; Ayanoğlu and Gökçe, 2007).

System dynamics is designed to model, analyze and improve socio-economic and administrative systems using a feedback perspective. Dynamic structured administrative problems are modeled by mathematical equations and using computer software. Dynamic constructions of model variables are obtained using computer simulations (Forrester 1962; Ford 1999; Sterman 2000).

The main principle of system dynamics is that the ongoing accumulation of the complex behavior of organizational and social systems (human, material, financial assets, information, biological and psychological states) is also the result of balancing and empowering feedback mechanisms. (Richardson, 1999).

System dynamics is an interdisciplinary problem-solving methodology that utilizes several significant thinking skills such as dynamic thinking and cause-and-effect thinking. System dynamics is a disciplined collaborative approach that could accelerate learning by combining a multifaceted perspective that provides insight into complex and interactive issues (Richmond 2010, Soderquist and Overakker 2010; Ferencik, 2014).

System dynamics deals with the behavior of time-dependent management systems in order to identify and understand system behavior with qualitative and quantitative models. It investigates how system behavior is managed by information feedback and how simulation and optimization could be utilized to design healthy information feedback and control policies (Coyle, 1996: 10).

System dynamics, as a method that investigates complex systems, offers a wide range of possibilities to analyze the total effect of policies by addressing the system as a whole (Öğüt and Şahin, 2012: 32).

The main approach of system dynamics is to project appropriate policies by examining the system behavior, rather than predicting system-related values. The subject matter of system dynamics is not an optimization operation. The aim is to research the behavior of the investigated system in the face of certain changes and to make decisions by determining the strategies to regulate this behavior (Erkut, 1983: 16).

STRUCTURE OF THE SYSTEM DYNAMICS MODEL

In order to analyze the dynamics of the actual system, system models are investigated. Models are simplified structures designed to examine the system behavior (Karnopp et al., 1990: 4). Models are constructed to better understand the economic performance of alternative decisions and their impact on environmental quality. Models are important tools in obtaining new knowledge (Ruth and Hannon, 2012: 4).

The model must have a clear objective, and this objective should provide a solution to a specific problem. The clear objective is the most important component of a successful model. A clear model, of course, could be inaccurate, too broad and difficult to understand. However, an explicit goal allows the users of the model to ask questions that demonstrate whether solving the problem is beneficial (Sterman, 1991: 5).

The dynamic behavior of the system consists of feedback mechanisms. The feedback loop is the basic building block of the system. Feedback corresponds to the interaction between cause and effect in systems theory. In system thinking, feedback is accepted as a proposition where each influence will be both cause and effect at the same time. Nothing is never influenced in only one direction. Feedback is a process where the initial reason ultimately influences itself by moving through a causal chain (Martin, 1997b: 6, Forrester, 1969: 13, Sterman, 2000, Senge, 2002).

Model components affect each other. Said interactions result in feedback processes. Feedbacks define the process. A component in the model causes a change in another component in the model, and these changes trigger further changes in other components in the model (Morecroft, 2015: 8).

A feedback loop must contain at least one rate and one level. If there is no rate and level in the loop, there will be no progress in time and a behavior could not be formed (Wolstenholme, 1990: 19).

The causal loop diagrams, a simple way to map the interactive elements in feedback systems, were first proposed by Maruyama in 1963. The purpose of the causal loop diagrams is to demonstrate which element in the dynamic system causes a change in the other. Causal loop diagrams are used to map the system structure in order to try to understand system behavior (Sezen and Günal, 2009: 302). These diagrams are also referred to as influence diagrams (Wolstenholme, 1990).

Initial system dynamics studies did not utilize causal loop diagrams. Loops were expressed by accumulation-flow diagrams and equations. Such representations are natural for engineers. Use of causal loop diagrams increasingly expanded and became popular to open the system dynamics approach to a wider population (Richardson, 1986: 158). Causal loop diagrams are a visual tool for feedback system designers (Morecroft, 2007: 39). Causal loop diagrams are used to understand the model in general, not in detail. Thus, they preserve their simple appearance (Pidd, 1996: 189).

There are two types of loops. The first is called a "positive" or "reinforcement" loop. It is shown with a "+" sign in the figure. The growth in the industrial sector increases the accumulation of capital, and the accumulation of capital reinforces the growth of the industrial sector. The second is called a "negative" or "balancing" loop. These are indicated with a "-" sign. For example, as the industrial sector grows, the need for labor increases, which reduces the amount of available labor. Decreasing available amount of labor, in turn, inhibits the growth of the industrial sector (e.g. due to the increase in wages), balancing this growth (Saysel and Barlas, 2001: 8).

Reinforcement (Positive) Feedback Loops

In positive feedback, the change that takes place creates an effect which strengthens the change in the component that caused the change in the process. For example, if you feel good about yourself and feel that you are successful in a field, you will work harder, because you will be more successful if you work harder, which will make you feel better and increase your chances of success in that particular field (McGarvey and Hannon, 2003: 6).

Balancing (Negative) Feedback Loops

In a balancing system, there is a self-control mechanism that works to protect a certain objective. Steering a car or riding a bicycle are examples of a balancing process. The objective of these processes is to move towards a desired direction (Senge, 1990). A deflating balloon could be given as an example for a negative feedback. Initially, the pressure in the balloon pushes the air in the balloon out at a high speed, which causes the balloon to deflate. As the air runs out, the balloon shrinks, the pressure inside and the rate of deflation decreases. This will continue until the deflation is complete. Negative feedback structures will continue until it arrives at a goal by creating smaller changes than itself in the same direction. The goal in this case is the condition where the internal pressure of the baloon is equal to the external pressure (Zhu, 2001: 5).

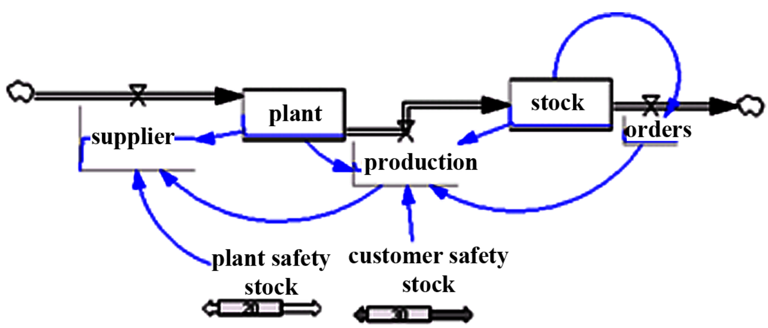
SD MODEL FOR SUPPLY CHAIN MANAGEMENT

In this chapter, a system dynamics model will be developed for supply chain management. The case study will be developed using VENSIM package program.

To manage a supply chain; 2 issues have a lot of important. Firstly supply chain must satisfy customer demand, but in fact predict customer demand is not an easy task. Other important issue is stock; level of stock is very important and manager's main responsibility is to satisfy customer demand with minimum cost, which is minimum stock. It is obvious that 2 target is contradictory. So managers needs a tool to analyze how their decision affect supply chain performance. This tool can be system dynamic and as a pocket program Vensim, Stella or other system dynamic packet program can be used. Because of ease of utilization, fast programming we choose Vensim pocket program.

It is appropriate to begin with a simple example. Let assume that plant is supplied by suppliers. After goods reaches plant stock, production phase begins. Then products are sent to product stock and then they are delivered to customers by customers' orders.

Figure 2. SD model



For beginning we assume customer orders are stable and is 100 good / week but in fact plant can only send what it has on its warehouse so

orders= MIN(100,stock)

Stock is finished product stocks and its value is

stock= ∑(production-orders, 100)

Plant Stock are goods to be use to product.

plant= ∑ (supplier-production, 100)

So we can now write production equation as:

production=IF THEN ELSE((orders-stock+customer safety stock)>0,

MIN((orders-stock +customer safety stock), plant), 0)

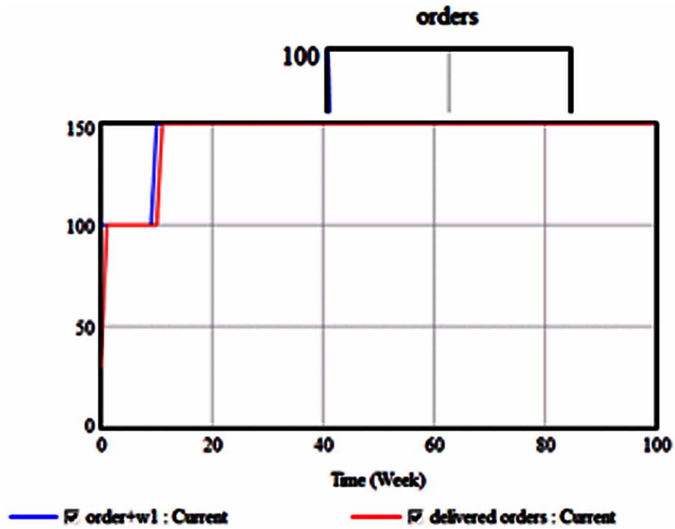
Before starting production, it is compared level of product stock, orders and safety stock than production level is determined but production level cannot pass plant stock.

After running model below results are obtained 20 unit of order are calculated but in fact 100 of order must be obtained so it is necessary to modify the model.

First order and delivery order are separated because customers' orders and delivered order to customer can be different. Also plant production plan is done considering current and current + 1 time. It is assumed that factory deliver the order in one weak. This is acceptable in general in industrial goods .

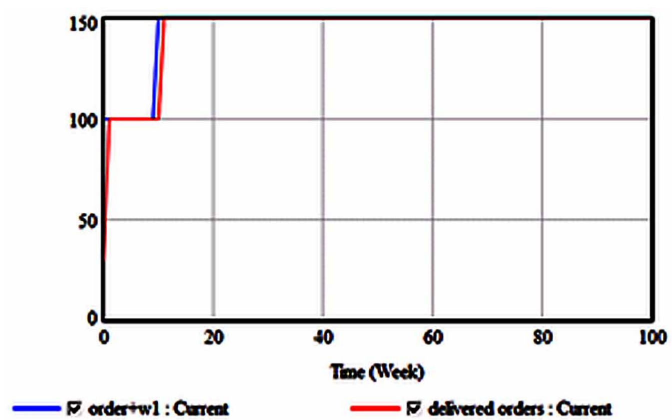
```
(01)        customer safety stock=30
(02)        delivered orders=MIN(orders,stock)
(03)        FINAL TIME  = 100  The final time for the
simulation.
(04)        INITIAL TIME  = 0  The initial time for the
simulation.
(05)        "order+w1"=100+STEP(50, 10)
(06)        orders=DELAY FIXED("order+w1", 1, 30)
(07)        plant= INTEG (supplier-production,100)
(08)        plant safety stock=100
```

Figure 3. Modified SD model



**For a more accurate representation see the electronic version.*

Figure 4. Graph of orders and stock



**For a more accurate representation see the electronic version.*

(09) production=IF THEN ELSE((“order+w1”+orders-stock+customer safety stock)>0, MIN((orders +”order+w1”-stock+customer safety stock), plant), 0)

(10) SAVEPER = TIME STEP

The frequency with which output is stored.

```
(11)        stock= INTEG (        production-delivered
orders,        100)
(12)        supplier=IF THEN ELSE(production+”order+w1”+orde
rs-plant+plant safety stock>0,production
        -plant+plant safety stock+”order+w1”+orders, 0)
(13)        TIME STEP  = 1        The time step for the
simulation.
```

As it is observed with this approache change in order are matched with change in delivered order.

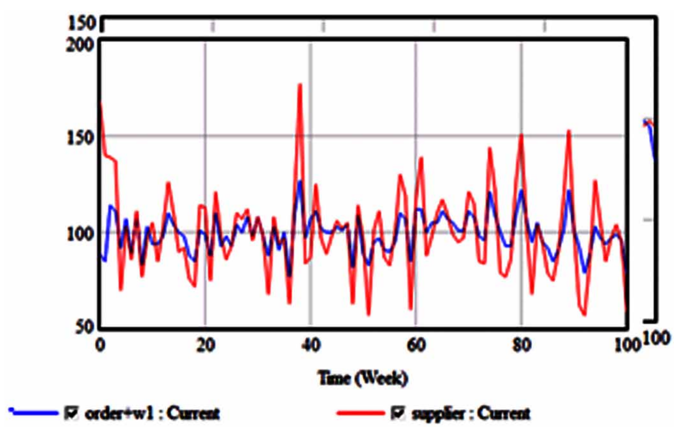
We can assume that order changes randomly with this equation by random normal equation

```
“order+w1”=        INTEGER(RANDOM NORMAL(50, 150, 100, 10, 1))
```

Delivered orders and order+w1 are obtained as in the graph so demand is satisfied. Now supplier side will be analyzed.

```
(14)        sup customer safety stock=50
(15)        sup plant= INTEG (sup supplier-sup production,100)
(16)        sup plant safety stock=        30
```

Figure 5. Order and delivered orders



**For a more accurate representation see the electronic version.*

Figure 6. Orders and delivered orders when orders changes randomly

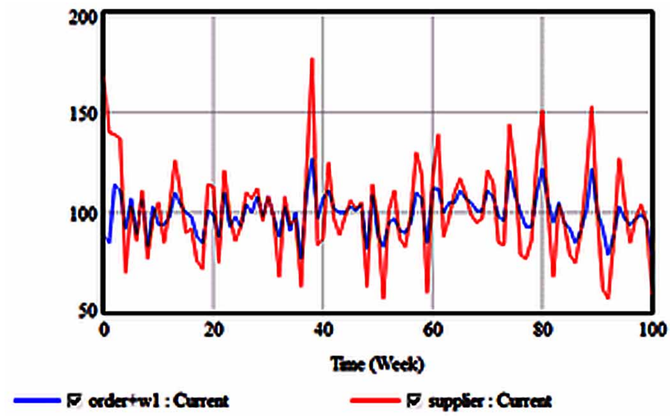


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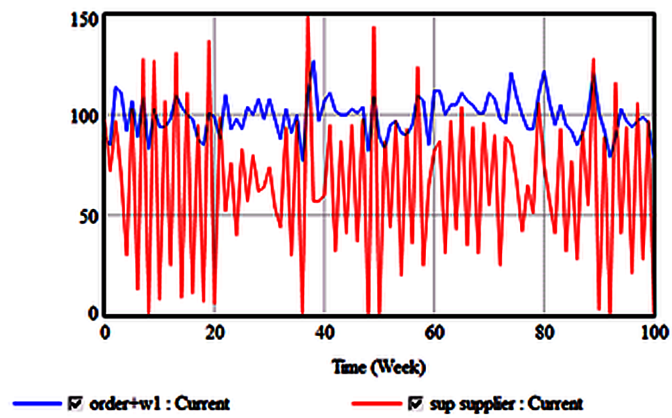
Figure 7. Graph of order and supplier



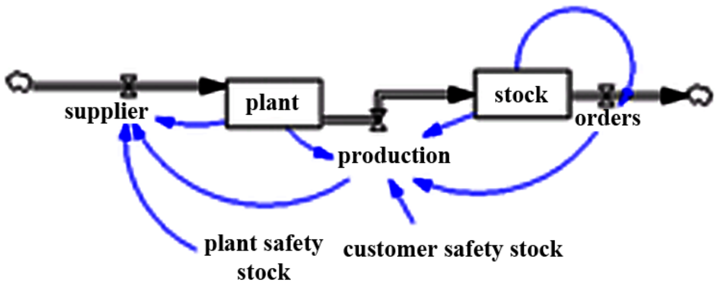
**For a more accurate representation see the electronic version.*

(17) sup production=IF THEN ELSE(supplier-sup stock+sup customer safety stock>0, MIN(supplier -sup stock+sup customer safety stock, sup plant), 0)

(18) sup stock= INTEG (sup production-supplier,100)

(19) sup supplier= IF THEN ELSE(supplier+sup plant safety stock>sup plant, supplier+sup plant safety stock-sup plant, 0)

Figure 8. Graph of order and sup supplier




```
(20)        supplier=IF THEN ELSE(production+”order+w1”+orde
rs-plant+plant safety stock>0,production -plant+plant safety
stock+”order+w1”+orders, 0)
```

CONCLUSION

As it can be observed that changes in customer order creates big changes in supplier’s supplier and manage of the production and procurement deals attention. As mentioned before to manage a supply chain; it is required to satisfy customer demand, with minimum stock but in fact predict customer demand is not an easy task so manager deals to manage customer satisfaction and consider effect of their approaches (thinking) on system performance.

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