Research Insights

Global Supply Chains and Multimodal Logistics

Emerging Research and Opportunities

Deepankar Sinha

Global Supply Chains and Multimodal Logistics:

Emerging Research and Opportunities

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Preface

Volatility, uncertainty, ambiguity, and complexity (VUCA) of global markets have made the task of supply chain managers challenging. Recent imposition of tariff of 25% by USA on steel and aero parts imports from China have led to changes in supply chain network of US based companies such as Boeing. Similarly, the downstream supply chain of Chinese firms has been disrupted. The landscape is likely to undergo further changes in view of Brexit, fluctuating oil prices and host of other factors.

Cost of goods, in global markets has three major components, namely, the ex-factory cost, logistics cost and taxes and duties. Export and import tariffs and restrictions are beyond the control and influence of the firms. Logistics cost constitutes 10 to 40% of the total landed cost of products in international markets. The production networks have shift from localized and regionalized pattern to global network designs. This along with the multi-country market has led to increase in multimodal movement of goods. The traditional approach of understanding is losing validity in the changed scenario. Logistics is one of the key factors of consideration in designing supply and distribution management system. Most of the frameworks in logistics, developed so far, have not distinguished between uni-modal and multimodal movement of goods. Multimodal logistics entails multiple stakeholders, terminals and nodes; and modes of transportation linking the two nodes. Goods hop and jump, that is, gets transshipped, may be more than once, between the source and consumption point.

Today a need arises to integrate the understanding of supply chain management and multimodal logistics for a full proof decision making in meeting customers' demand and maintaining growth of the company. I have attempted to meet this objective in my book *Global Supply Chains and Multimodal Logistics: Emerging Research and Opportunities.*

This book has seven chapters. The first chapter follows the tradition in book writing and is titled as "Introduction to Supply Chain Management and Multimodal Logistics". This chapter sets the condition for an integrated approach to the discussion on the theme of the book. Here I have attempted to thread together the macro level supply chain (SC) concepts to micro level logistics issues. It begins discussion on the definition, structure and elements of supply chain of a firm. This section highlights that at one end structure of supply chain networks (SCN) evolves as the firm grows while this gives rise to *complexity* making the supply chain management (SCM) challenging. But what drives the complexity has been explained in the following sections. The roles of drivers, actors, enablers and inhibitors of SC have been explained to say what would be the consequences on account misdealing of these factors. Though the concept of SC drivers in not new, here the drivers have been split in to two categories, namely, the *strategic and the operational drivers*. The mission, vision, product range and target customers are the strategic drivers and have been explained with relevant examples. This concept is then linked to the concept of operational drivers such as inventory and facility. It goes to say the inventory decisions are linked to the product strategy of a firm. It stresses the super-ordinate goal of a business that *customers come first*, and then the cost.

The actors have a significant role to play and the supply chain has been described from this perspective as well. A customer driven supply chain is different from producer driven supply chain and as such the decision making frameworks are different too. This book introduces the concept of *Available-to-promise (ATP)* and *capable-to-promise (CTP)*, meaning that a firm would commit to the extent it is capable to produce and supply. These concepts integrate the customer driven supply chain to the producer driven supply chain. A supply manager has to; thus, view both the perspectives in an integrated manner instead of looking it as silos.

Supply chain performance is not only dependent on internal decisions and business partners' performance, but also gets effected by external factors such weather and country regulations. These aspects have been summarized in the section – *Enablers and inhibitors* of supply chain.

The consequences of a poor SCM, namely, bullwhip and snowball effects have been illustrated with examples and the remedy briefed. The remedies recommended by the experts so far have focused on discrete mechanism of collaborative planning and information sharing; but researchers have showed that snowball effect is significant in a highly integrated SC. Here I have introduced the concept of *system thinking*, professed by J W Forrester and Peter Senge, to address this issue.

The discussions on the topics mentioned so far led to identification of objectives of supply chains. This chapter describes the different objectives – customer centric SC; flexible, lean, green and resilient SC. It warns the supply chain managers that in the process of making SC lean it may lose the power of being resilient. This section explains the consequences of *global-reporting-initiative* (GRI) on supply chain of firm. Here I have introduced the concept of a *synchromodal* planning approach towards transport orders to aid simultaneous minimization of cost, delay and emissions.

This chapter gives a supply chain planning matrix linking supply chain strategies with different business strategies. It shows how push SC strategy is relevant to "make-to-stock" strategy while pull is relevant to "engineer-to-order". It distinguishes between "make-to-order" and "engineer-to-order" strategies to explain the change in SC strategy in these two cases respectively.

This chapter ends with discussion on global logistics management. It brings in concept of multimodal transportation to explain the uniqueness of global supply chain. This section relates *international commercial (INCO) terms* with the logistics responsibilities of seller and the buyer.

SC behaviour is dynamic as it tries to adapt the changing conditions of market and environment. As such, in the process of adaption it gets complex as new products or new product features are added, suppliers are added, removed or revived, distribution channels are reorganized. In other words the *Strategic, Dysfunctional and Structural complexity* of supply chain increases. This aspect has been dealt in detail in Chapter 2 of this book. This chapter illustrates the different structures of supply chain networks; the drivers of complexity and perspectives to manage the complexity of SC. Here I put forward the point that when business grows links with supply chain partners increases, while there is slow down these links stand redundant. That is there shift from strategic to dysfunctional complexity. This chapter discusses the *system and process perspectives* to manage SC. It provides some recent findings on *the measurement of structural complexity.* This chapter introduces the concept of *entropy* to determine complexity based on *information theory*. This is further extended to determine *Operational or Dynamic Complexity* of SC. This chapter introduces different metrics, namely *supply-chain-length (LSC), modified-flow-complexity (MFC), index-of-vertex-degree* (I_{vd}) *and link-tier-index (LTI) with examples* for clear understanding.

Chapter 3 discusses various facets of supply chain strategy. It sets the condition for implementing different strategies, namely make or buy; supply to stock or order; cost efficient or responsive SC; push or pull SC. This chapter integrates *SC strategy* with *product life cycles*. It puts forward the need for *co-creation with supplier*, and assessment of their SC capabilities needed for different stages in product life cycle. This chapter discusses SC strategy in terms of *time-inventory-cost trade-off* and implementation of *just-in-time (JIT)* mode of operation. The chapter brings out the need for *risk hedging strategy* and *floor-ceiling pricing strategy.*

Chapter 4 discusses on the ways to implement SC strategies. This chapter provides the basis to tradeoff between service levels and inventory turnover ratio. The discussions have focused on the conventional inventory decision models as well as *heuristic approaches* such as *Silver-meal method*. This chapter introduces the concept and need for *adaptive inventory control* for non-stationary demand. This chapter calls for importance of *artificial intelligence* in managing uncertain demand. An *outsourcing decision matrix* based on internal and external competency and capacity has been provided. The different types of contracts – cost and revenue sharing contracts, payback, buyback, and rate contract have been discussed. This chapter introduces the concept of *Keiretsu* approach towards integration of suppliers. The need for vendor-managed-inventory (VMI) and material-requirement-planning (MRP) have been also stressed here. Global supply chain management is governed by *international incoterms (INCO terms)*. The concept and essence of INCO terms have been discussed in to give clear understanding of the role of supply chain and logistics manager in implementing SC strategies for global supplies and distribution. This chapter provides the *global sourcing framework* in terms of 5 elements: "<HS code, price, currency, INCO term, and named place>".

Chapter 5 focuses on multimodal transportation, a means of global movement of goods. This chapter identifies *fourteen dimensions of multimodal transportation*. These dimensions impact design of logistics chain. These dimensions are – cargo mix dimension, nodal mix, capacity, infrastructure, demand, quality of service, financial, competition, information, environment, risk, statutory and ethical dimension. This chapter introduces the concept of quality of multimodal transportation and proposes a *mathematical model for multimodal transportation planning and route selection.*

Chapter 6 is on "Management of Logistics Systems and Operations". This chapter discusses the principles of packaging and material handing; warehouse operation and compares the different modes of transportation. It explains the significance and concept of *containers* in international business. This chapter provides a transportation choice framework and explains the factors affecting quality of multimodal transportation. This chapter introduces the concept of *opportunity cost* in deciding mode of transportation. The *dynamics of shipping* including types of *chartering* have been explained. A section on *humanitarian logistics* explaining its distinction from the commercial logistics has been provided.

The conclusion gives the 10 plausible areas where further research needs to be carried out. The areas primarily relate to integration of internal and external capacities to develop a *dynamic outsourcing* strategy; a SC strategic framework to address the impact of *interstate relations* (such as current USA – China trade relationship) on supply chain of a firm; development of *lead metrics* to avoid SC disruption; manpower planning in view of sustainability and GRI recommendations; relevance of resource-based-view (RBV) in supply chain in light of *disagreements* between Barney and two other authors; Use of *artificial intelligence in predicting supply chain behaviour of a firm*; container freight dynamics in view of *negative freight rates*; and decision framework on sourcing methods. This chapter introduces the concept of *ontology* to be applied in the field of multimodal logistics.

This book will be help students pursuing *MBA and industrial engineering*. The frameworks can be learned and applied on their induction in the industry. As such the *industry practitioners* can also use this book for reference to any kind of problems. The chapters provide literature references and discuss the merits and gaps in existing research. This book will help researchers, in the field of operations, supply chain and logistics management, to under the concepts, identify the major works done so far and the further scope of research work.

I am grateful to my teachers, parents, my wife and daughter, my elder sister and brother-in-law, my in-laws and their family, my colleagues, and friends for enabling me to complete this book. My parents who are no more in this physical world have been a constant source of inspiration from the learning I received from them. I thank my teachers – Prof. R N Banerjee (my research guide), Prof. Biswajit Mahanty, Dr. P Purkayastha, Mr. S N Chakravarty, and all others have taught me to be ethical, sincere and develop a sense of deep belongingness in whatever I do. I am grateful to my wife Kajal and my daughter Dipanjana who ensured that I get all conform at home and support for completing this work. Sanchita (my elder sister), B.S. Kumar (my brother-in-law), K.K. Sarkar and Pratima Sarkar (my in-laws) and their family - Shantanu and Maitryee; Subhangam and Sreemanto; my niece Shruti and Sneha, Prasenjit have always motivated me for any assignment

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I thank IGI Global for supporting the concept behind this book that cuts across the supply chain community and for the cooperation extended to me in completing this work.

Chapter 1
Introduction to Supply Chain Management and Multimodal Logistics

ABSTRACT

This chapter provides an understanding of basic essence of supply chain management. It introduces a multi-dimensional facet of supply chain management. A typical supply chain has at least three entities, that is, the supplier, the firm, and its customer. The inter-link between these three entities comprises three primary components of a supply chain, namely, the inbound or upstream supply chain, internal supply chain, and outbound or downstream supply chain. However, in a real-life scenario, many firms (especially in case of large and complex firms), the suppliers, and production centres are more than one. This increases the complexity of the supply chain structure. This concept has been introduced in this chapter. The drivers of supply chain have been categorized under strategic and operational drivers. This aspect has been explained, with examples. The chapter discusses the enablers and inhibitors of a supply chain of a firm. It proceeds to explain the issues in assessing and integrating the drivers, enablers, and inhibitors in the supply chain planning process. Bull whip and snow ball effects are two important outcomes of an inefficient supply chain. These concepts have been introduced

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here. Finally, the chapter concludes by laying down the objectives and the strategies of supply chain management. It prioritizes the focus of supply chain management, stating that customers come first followed by cost optimization. The chapter discusses on the ways to make supply chain agile and flexible. Supply chains are always prone to disruptions; hence, this chapter talks about a resilient supply chain. Next to customer, cost is an important element that enables a firm to keep its price competitive and be profitable. Here the concept of a lean supply chain has been discussed, a way to minimize waste and hence reduce cost. Supply chain management varies with firms' business strategy. The firm may choose to follow either a cost-leadership strategy or a differentiation or a focus strategy and thus would accordingly adopt push or pull or push-pull (supply chain) strategy. In case of cost-leadership strategy, the firm is expected to follow "make-to-stock" (operations) strategy; in case of differentiation strategy it would adopt "make-to-order" strategy; and for focus strategy the firm embraces "engineer-to-order" strategy. This chapter discusses these aspects to correlate the different dimensions of business and its supply chain management. Firms now are focussing on global operation to leverage on opening up of economy, enabling them to lower the cost of operations and achieve the desired quality. Besides, globalisation has also led to widening of market coverage. A brief introduction to global logistics management has been made in this chapter to emphasise on operationalization of a firms' global supply chain.

SUPPLY CHAIN: DEFINITION, CONCEPT, AND ESSENCE

A supply chain is a network of nodes that ensures supply of inputs to operations of a firm resulting in production of goods and services and supply of these goods and services to the customers and consumers of the firm.

Figure 1 illustrates a simple supply chain with two nodes connected to the firm.

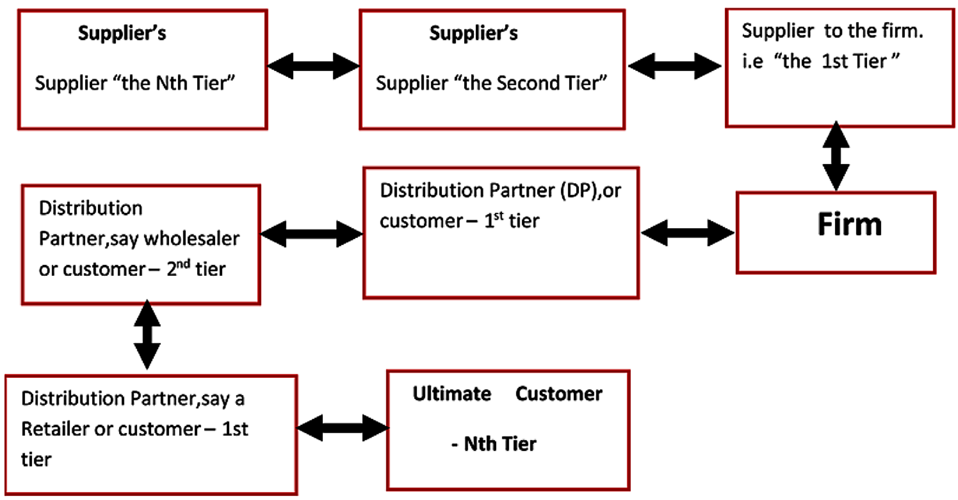
This supply chain has one supplier and the firm sells goods directly to the end customers.

However, there can be more than on tier of suppliers to a firm and more than one entity in the distribution of finished goods to the end customer. The initial nodes in the N^{th} tier represent the original suppliers and rest of the nodes in the upstream supply chain represents the assembly points.

Figure 2 depicts such a supply chain

Figure 1. A simple supply chain

Figure 2.



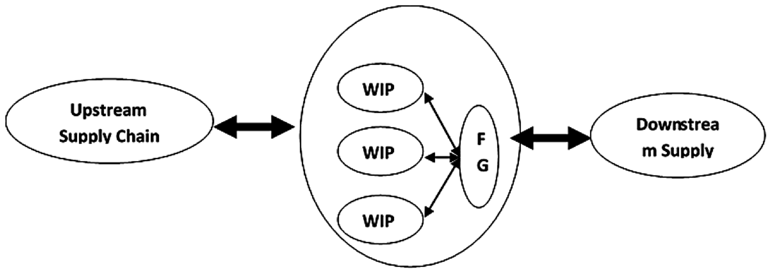
A supply chain of a firm has two legs; one, the upstream supply chain and the other, downstream supply chain. Nodes that ensure supply of inputs comprise upstream supply chain while the nodes that distribute the finished goods comprise downstream supply chain.

Besides, the production of goods and services may take place in a distributed environment, as shown in figure 4.

This figure shows that that firms production of intermediary goods or WIP (work in progress) takes place in three different units while the finished goods (FG) are produced in the fourth unit. These units can be in same or

Figure 3. Upstream and downstream supply chain

Figure 4. Supply chain of firm having different production units



at different locations. These units constitute the firm's production network and flow of goods in this network is termed as *internal supply chain*. The entities forming the supply chain of a firm can be divided into *upstream* partners (i.e raw materials or input suppliers) and *downstream* partners (i.e the finished goods suppliers and associated partners such as ware houses, distribution centres and the like). These partners are arranged in levels or tier in a supply chain. The tier (of partners) closest to the firm is the first tier (or labelled as tier-1) partners. The partners of the first – tier entities represents the second tier and so on.

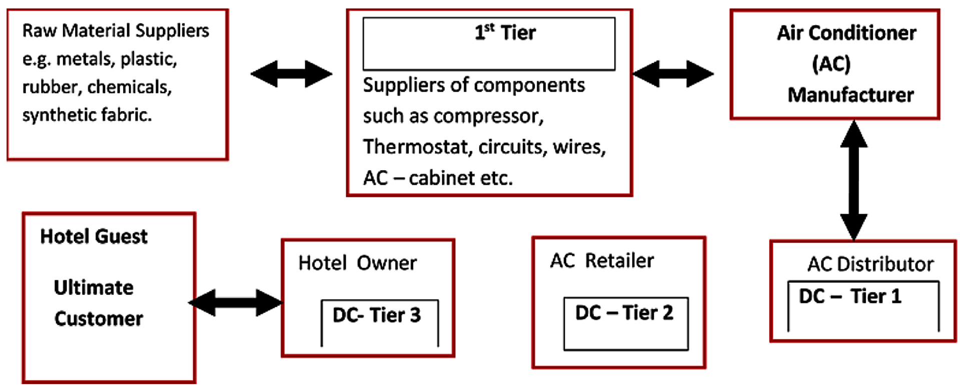
The supply chain can, thus be represented as shown in figure 5.

Figure 6 illustrates a typical supply chain of an air-conditioner manufacturing firm. The firm ensures its supplies from tier 1 suppliers who in turn get their supplies from their suppliers. There can be more than one tier 1 suppliers, for example suppliers of electrical component, circuit boards, thermostats, cabinets etc. The figure illustrates that the firm sells its machines through a distribution channel comprising distributors and retailers to their customers say hotels.

There can be more than one supplier and distributor in a tier in upstream and downstream supply chain of a firm. Supply Chains are not restricted to manufacturing organization and can include service operations such as ports, health care, educational institutes or even government bodies, .i.e., for any type of operations.

Figure 5. Upstream, internal, and downstream supply chain

Figure 6. Example of a typical supply chain of an air-conditioner manufacturing firm



Example: A Sea Port Service Supply Chain

Figure 7 illustrates a typical supply chain of a sea port. The upstream partners comprise the resource suppliers such as crane – manufacturer, stevedores, and port operators; and services include cargo handling at berths and yards. The shippers and carriers are the ports' customers.

Supply Chain Structures

Examples of different supply chain structures are illustrated in figure 8.

The structure of a supply chain can be of different types as shown in figure 8. Each of these structures varies in terms of number of tiers; number of vertices (nodes) in each tier; and the edges (links) connecting the nodes. These elements (vertices and edges) give rise to the structural complexity of supply chains (Lambert & Cooper, 2000). The structure of supply chains need

Figure 7. An illustration of a supply chain of a sea port

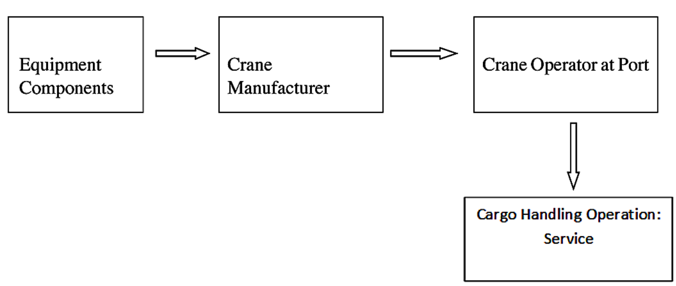
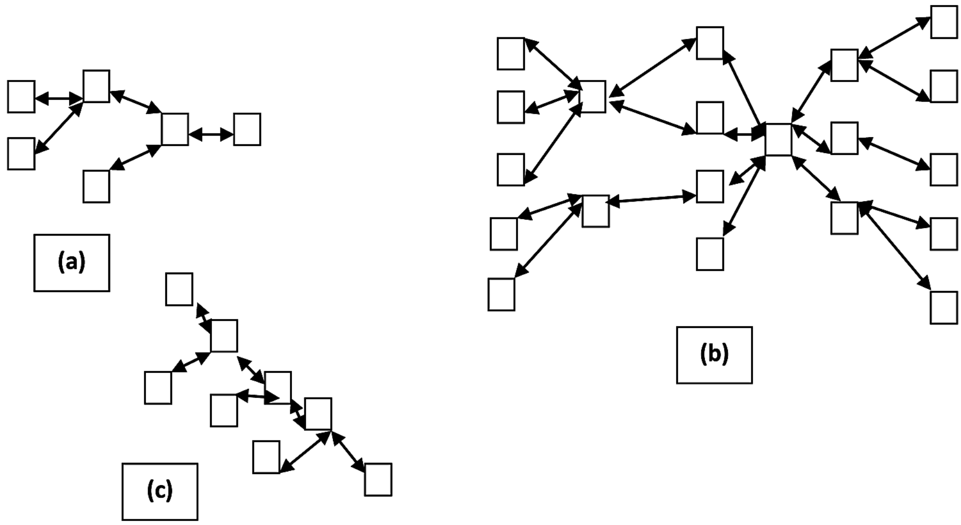


Figure 8. Examples of some supply chain structures



to be optimal, else it affects the flow of material in a supply chain. Hence, an optimal number of tiers and nodes are essential for network design of a firms' supply chain. Chapter 2 deals with "structural complexity" in detail.

Supply Chain Drivers

The performance of supply chain is measured in terms of its efficiency and responsiveness. The drivers of performance include strategic drivers, operational drivers and support drivers.

Strategic Drivers

The mission, vision, product range and target customers are the strategic drivers that affect design of a supply chain. It is related to firms' capability to implement the right strategy that in turn impacts its performance. The supply chain strategy relates to design of a product (modular, integrated or hybrid), make or buy decision, sourcing, targeted quality of service (QoS), and pricing of products and services.

The design of a product affects the "make" or "buy" decision. In a modular product, the firm has an option to choose which module or component to make and which one to outsource. In case of integrated product the options get limited. A firm need to identify the components and operations it wants to perform in-house and the ones it wants to outsource.

For example, the design of *Apple iPhone* is done in-house while manufacturing is outsourced. Outsourcing decisions are crucial as it could lead to drop in efficiency. In November 2016 Apple confirmed that its iPhone 6S handsets, manufactured in September and October in the same year, have battery related problems. The firm had to offer free repair and replacement of the battery unit. This calls for relook into the decision related to outsourcing or the sources from which the supplies are made.

A firm has to decide on the quality of service (QoS) it commits to its customers. The different dimensions of QoS include cost, time to deliver, customization or personalization, return of goods and their combination.

There are companies who offer low cost deliveries where cost of item gets priority over other dimension. For example, a book store may agree to sell a book at a discounted price but delivers it within a time period, say 10 days. Whereas another book store may sell without discount but delivers in a days' time. Amazon has free one day or two day delivery for its members whereas it charges an additional amount for same day deliver from non-members. There are firmsthat offers customisation of products and services, to different extent, to their customers. For example, *Maruti Suzuki*, a leading car manufacturer in India, offered a scheme termed "ïCreate" to its customers allowing them personalization of around 90 different aspects related to exterior and interior features, within the acceptable time limit. The company also offers an "A la carte option" to the customers to choose the accessories. The objectives in all these cases vary and the performance of supply chain affects the outcomes. An incompatible or unrealistic strategy will affect the customers' satisfaction. For example, *Domino Pizza* promises 30 minute delivery, else delivers free of cost. This has caused several deaths of its delivery persons as they had to rush within the busy city roads in many countries. This type of *social* implications is also cause of decreased performance of supply chain in long run. Similarly the case of *Volkswagen* is an example of a firms' failed promise at a desired price to its customers. In 2015, Volkswagen, a leading car manufacturer, ended up paying $30 Billion in penalty, compensation and corrective actions for not adhering to standards of quality of emissions. They cheated the environmental protection authority of USA by manipulating the software to detect emissions. The company faced drop in both shares and sales. This failure not only had financial implications but also led to devaluation of brand and had serious human impact. It is reported that excess emissions may have caused 38000 premature deaths across the globe. QoS is not only about technology and service but also about sustainable business, meaning implementation of a *green* and *ethical* supply chain.

In April 2018, *Tesla* acknowledged that it is unable to meet the production target of manufacturing of its Model 3 sedan electric car due to problems in automation and bottlenecks in production system. The firm had to go for downtime of its production units. Thus it is important that a firm need to have *flexible and agile* supply chain to ramp up production and adapt change in both volume and variety of their products.

The increasing trend in adopting electric cars have given rise to a new dimension to its impact on environment, as at present, there is lack of environmentally safe way to recycle the lithium ion batteries (Sinha, 2018). If the car manufactures do not devise ways to recycle the car batteries, their supply chain will not be sustainable in long run. Thus strategy on *return and recycling* are important to improve performance of supply chain of a firm.

Pricing has a significant impact on the performance of supply chain, especially in terms of responsiveness. Firms base the prices of their products and services based on value it commits to the customer. The value has been described as the QoS earlier. Customers pay for the utility it seeks, and any failure on the part of the firm will lead to drop in sales and prices, barring cases of monopoly or essential goods.

Operational Drivers

The operational supply chain strategy depends on the nature of demand of the product (Fisher, 1997). Products can be broadly categorized as functional and innovative products. The uncertainty in demand of functional products is much less compared to demand of innovative products. As such, a supply chain manager would aim at minimization of cost in case of functional products, i.e., is an *efficient supply chain*. For innovative products the supply chain need to be *responsive,* meeting uncertain demands of customers. The major challenge in this case is about holding inventory of goods to be responsive while at the same the demand for goods is uncertain as these products have shorter life cycle.

The key aspect in putting all these strategies together is management of inventory. Inventory has different perspectives namely, quantity, storage and stowage. Inventory acts as shield in times of increased demand and disruptions. But it is a bane when inventory remains unutilized and becomes obsolete. A firm aims at holding optimal inventory in case of functional products, but may have additional buffer stocks for innovative products. This is especially due to the difference in lead time to deliver functional and innovative products. Fisher (1997) estimated that functional products have lead time of 6 weeks to 1 year whereas innovative products have lead time of 1 day to 2 weeks. As such in case of functional product the objective is to shorten the lead time as long as it doesn't increase the cost; whereas in case of innovative products the supply chain manger looks for aggressively reducing the lead time.

The quantum of inventory, its variety and dwell time dictates the facilities required for ensuring the right performance (responsiveness and efficiency) of supply chain. Packaging of goods and materials is an important element that dictates the type of facility and transportation carrier required to move the goods from origin to the destination. For example, marine products such as fishes packed in ice filled insulated boxes can be kept in a common non-temperature controlled warehouse, else need to be stored in a reefer container or in a temperature controlled warehouse. Reefer containers can be stowed in open yards with power supply facility. The containers can be transported in trailers that are not suitable for other forms of packages such as boxes, cartons, pallets and other similar unit loads. A unit load can be transported by different modes of transportation such as rail, road, water and air. Liquid cargo can be moved as unit load in drums, barrels and tank containers or in loose form in tank carriers or through pipelines. Different modes of transportation vary in terms of speed and time, cost, transit time variability and resilience. Thus choice of right transportation is crucial to ensure the desired performance of a supply chain.

Chapter 3 deals with strategic and operational drivers in detail.

The Actors in Supply Chain

Dani (2015) in his book titled " Food supply chain and logistics: From farm to fork" identifies and lays down the role of different actors involved in a supply chain. Though the book addresses food supply chain management the concepts can be applied across different supply chains. The different actors include raw material or input suppliers, input processors or producers, traders or distributors, wholesalers and retailers, logistics and other third party service providers. The supply chain can be viewed from different actor perspectives. Say, a "commodity-producer" focussed supply chain, or "customer –driven" value chain. In the former case, the firm focuses on bulk purchases and make-to-stock production of goods. Here the firm undertakes strategic partnerships with input suppliers or buys it as commodity items on future contracts or resorts to online reverse auction. In future contracts the firm agrees to buy the item in future at prices agreed at the time of finalizing the contract with the input-supplier. That is, the delivery and payment will be made in future at future-price agreed today. While in case of customer-driven supply chains, the thrust is on customization and functions on the principles of collaboration and coordination. Collaboration between actors becomes more significant for products with short lifecycle as responding to the change in producy-variety is a challenge (Simatupang, & Sridharan, 2002)..

Available-to-promise (ATP) supply chains aim at integrating customer demand with input-suppliers' capability. ATP integrates customer order with capable-to-promise (CTP). This form of supply chain ensures delivery of right material, in right quantity to right customer at the right time. In other words, a firm would commit to fulfil that portion of orders which it is capable of fulfilling (Framinan & Leisten, 2010).

Logistics service providers are important actors in any supply chain. Their significance are greatly felt with regard to performance of the e-commerce companies (Joong-Kun et al., 2008) such as Amazon or JingDong who promise their customers same day delivery or two day delivery or even 3 hours delivery (a promise by JingDong). Their efficiency revolves around their warehouse network (logistics centres) and delivery systems (Yu et al.,2016). Ramanathan (2010) opined that the relationship between logistics performance and customer loyalty is more pronounced in e-commerce companies than in any other sector. The logistics capacity is an important determinant of logistics performance in e-commerce market (Joong –Kun Cho, Ozment et al., 2008).

Wholesalers and retailers are the actors who enhance market coverage, availability and convenience. A retailer of a particular firm manages competition between the different offerings of the firm, while a multi-brand, multi-product retailer need to address the supply chain issues across different companies with different products. Brun, & Castelli, (2008) suggested a supply chain strategy segmentation based on 3 drivers, namely product, brand and retail channel for retail sales in fashion industry. The authors suggest that control over retail channel influence the company performance.

The major issue arising out of increase in actors in supply chain is that of coordination. Lack of coordination leads to bull-whip (amplification of customer demand up in the supply chain i.e., from retailer to the firm the variability in demand order increases) and snowball effects (amplification of disruptions across the supply chain), causing disruptions in supply chain. While authors have suggested integration of actors as the remedy for bullwhip effect, Świerczek, (2014) suggested that integration has positive impact on snowball effect. That is, the snowball effect may be more pronounced in highly integrated firm. Thus, the major challenge lies in managing disruptions. The internal integration of the firm is vital to its supply chain integration efforts. It acts as a crucial link between the suppliers at one end and the customers at the other end (Flynn, et al.,2010).

The Supply Chain Flow Enablers and Inhibitors

The flow in a supply chain gets disrupted in absence of top management commitment, effective organization structure, lean, flexible, agile, green and integrated business processes, collaboration among nodes, right contracts and agreements, trust and mutual concerns. A supply chain is also affected by security protocols and country regulations. Absence of these factors weakens the links in the supply chain; and inhibits the flow and performance of a supply chain. Besides, flow of goods is also hindered due to natural calamities and other force majeure incidents.

Impact of Drivers, Enablers and Inhibitors on Supply Chain

The drivers, enablers and inhibitors impact the performance of supply chain. Bullwhip and snowball effects are the negative effects.

Bullwhip Effect or Whiplash Effect (Lee, et al, 1997).

Supply chain may experience a scenario where the difference between the actual sales and order placed with the supplier tend to be very large, and this variance propagates upstream and gets amplified. The variance between the actual sales and order placed with the supplier refers to the demand distortion. This distortion, in the supply chain, results in increased inventory, obsolescence of inventory and fluctuations in production schedules. This phenomenon is experienced due to incomplete information sharing among the nodes, i.e, the retailer, wholesaler, dealer and manufacturer. A retailer is the direct connect with the end customer, yet places larger orders compared to its regular sales as the wholesaler may have announced a price discount for bulk purchase or the retailer may like to achieve economies of scale in transportation (of bulk quantity). This is termed as order batching.

The retailer tends to increase its order size if has experienced shortfall in supplies from the wholesaler in recent past. The wholesaler may have also experience similar shortfall against previous orders placed with the distributor and hence may increase his order size as well. Similar experience of distributor will lead to further amplification of order size. This is termed as *rationing game*.

There could be other reasons, for bullwhip effect, such as *demand signal processing* and *price variations (*Lee, et al.,1997). In the former case, a retailer may experience increased demand over few weeks in the past and expects the trend to continue. Hence places order of larger dimension with the wholesaler and the same repeats with amplifications upstream.

P*rice variations* refer to the possibility of price of a product being not stable and fluctuate over the time. A retailer, when the prices are lower, may place bulk order. This causes the inventory to go up disproportionately in the supply chain.

All these effects characterize the market place and have a market force effect. The nodes in the supply chain react to the changing market forces and this results in bullwhip effect unless there is distinct information flow between the nodes. The information relates to the availability of actual sales (and not orders placed with supplier) and available inventory in each node.

The term bullwhip effect is coined based on the shape of the demand distortion in the upstream supply chain (figure 8).

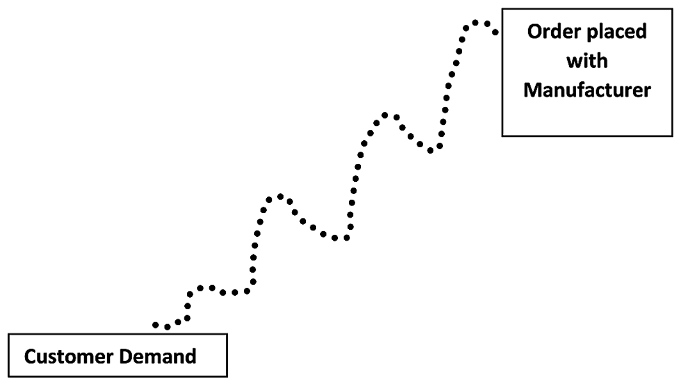
The effect represents the lashing of a bull whip. It represents the way the demand variation gets amplified upstream.

Snowball Effect

Supply chain is an interconnected system of nodes. The consequences of risk in any one node are likely to be transmitted to the subsequent nodes. The impact of these consequences is likely to get amplified (have stronger effects) in the subsequent links and is referred as *snowball effect*.

This effect can be explained in terms of three theories – network theory, contagion theory and the theory of systems thinking. Network theory refers to the inter-node dependence and integration. The network can have different topologies as discussed in the section 2 above. The links between the nodes are in terms of different levels of contracts between the nodes to ensure material flow, information and financial flows. Any disruption in a node will cause disruption in subsequent nodes. For example, Honda car manufacturers

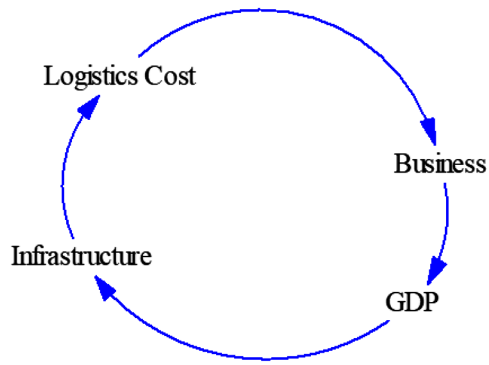
Figure 9. Bullwhip or whip lash effect



in Thailand faced production disruptions due to flood in 2012; this caused stoppage of production of components, of the car, in factory located in India. Contagion theory differs from the network theory in terms of defining the inter-node linkages. It states that if two nodes are linked, disruption in one would lead to significant increase in another, however the channels of transmission of disruption may differ between nodes and links. For example, the supplies between two nodes located in two countries may get disrupted due to trade linkages between the countries. For example, the recent trade war (in 2018) between China and USA led to disruption in Boeing factory in USA which gets supplies from Chinese manufacturers. Thus, in this case, trade linkages between two countries are the channel of contagion or transmission of disruption. Similarly other channels of disruption could be force majeure causes, political, social and economic imbalances or environmental factors. System thinking, professed by Peter Senge, uses the concept of feedback - reinforcing or balancing, in cause and effect analysis. It states that while a cause gives rise to an effect, there can be reciprocal flow of influences from the “effect” to the “cause”. For example, logistics cost decreases if transportation infrastructure of a country improves. Reduced cost results in increased business. This in turn increases the gross-domestic-product (GDP) of the country. If GDP increases, government spends more on infrastructure which in turn decreases the logistics cost (Figure 10).

The tenets of systems thinking, in particular its concept of feedback, have been used to complement the contagion theory with necessary conceptual considerations on the amplification of disruptions in the transmission process. The concept of feedback refers to any reciprocal flow of influence. In other words, it posits that each influence is both cause and effect and nothing is

Figure 10. Cause and effect relationship: A system thinking approach



ever influenced in just one direction. Instead of a direct cause and effect relationship, one should see relationships in a particularly indirect sequence. Consequently, it is important to see reality systematically as circles of influence rather than straight lines (Senge, 2004).

Every circle tells a story, showing how the structure creates a particular pattern of behaviour; or, in case of a complex structure of supply chains, several patterns of behaviour, and how such patterns might be influenced. The reinforcing feedback causes a disruption to snowball and hence we observe "snowball effect" in the transmission of disruptions. Senge (2004) points out that the reinforcing feedback is one of the types of feedback process that is the engine of growth or accelerating decline.

Świerczek, (2014), showed that the intensity of integration of supply chain may contribute to the snowball effect in the flow of disruptions in the materials and information. He demonstrated that the impact of integration is significant and positive on the snowball effect in the forward as well as backward transmission of disruptions. While the span of supply chains integration affects negatively the strength of disruptions in the forward and backward transmissions in the material and information flow. However, the strength of disruptions in the finance flow is not dependent upon the intensity and span of supply chain integration.

Objectives of Supply Chain Management

In view of the discussions made in earlier sections the objectives of a firms' supply chain can be described as:

Customer Centric

Supply chain management should be directed towards the customers' requirement, it wishes to serve. Customers seek five different utilities. These are the form, place, time, possession and image utility at the right price. Form utility refers to the specification customers lay down for their products and services. A firm needs to adhere to the specifications and quality standards to meet this utility. The right specification and quality of the produce is best achieved through right design, right inputs, right process and right packaging. Place utility refers to the point of delivery of goods and products to the customer. At present, with the increasing trend of e-commerce, this utility is of paramount importance. The concept of delivery is now door-to-door, where in the customers are not interested in understanding of how many nodes the goods crossed to reach their door step. Earlier it was, instead, port to port or terminal to terminal, where a customer would take delivery from airport or sea port or from the transporters warehouse or depots. The last mile delivery was the responsibility of the customers. This has made supply chain managers rethink and redesign their distribution system to meet customers' requirement. The last mile service providers in many cases are fragmented and calls for intensive network controls. The time to deliver in the last mile is not influenced by transit time; instead it is affected by the pickup and delivery time. Thus, here the performance is influenced by the delivery process and not carrier performance alone.

At present customers look for delivery at the right time. That is, delivery not before a certain time or beyond a certain time. A time window is specified. There is a shift, towards vendor managed inventory (VMI) and just-in-time (JIT) delivery, from self-managed inventories. The customers are not willing to keep inventory, instead want delivery at right time that minimizes inventory holding cost; and at the same time avoid stock outs and production stoppages.

In the downstream supply chain, the supply chain managers keep decentralized inventories close to the market, in order to be responsive and efficient. It is well known that decentralization may cause operations to run at sub-optimal levels.

In many cases, selling of a product does not end with delivery alone, it includes un-packaging, installation, trial runs, commissioning and warranty support. A customer may refuse possession of products if any one of these is not met or till it is met. A supply chain manager need to ensure that the possession utility of the customer is satisfied as promised in the firm's

QoS assurance to the customer. Brand development is not the job of market professionals alone; it is an outcome of meeting the customers' expectation. Supply chain performance has a significant impact in creating brand image of the firm's product and services. This utility leads to reinforcement of customer's preference of a firm's product and their recommendation of the same to their peers.

Flexible

The increase in demand for products calls for ramping up of firm's production to meet this increased requirement. A flexible supply chain will enable a firm to increase its supply of inputs, increase in rate of production and supply of the finished goods to the customers. A supply chain manager may increase number of suppliers or have agreements to enhance supplies to meet increased demand. Hence, a robust supply chain needs to be flexible to adjust to the varying demands of products and services. Flexible supply chains focus on building redundancies or reserving capacities to meet with demand volatility. This concept has been construed as agility (in lieu of flexibility) of supply chain by some authors (Christopher & Towill, 2000).

However, the challenge of a supply chain manager lies when the demand of products decreases, the suppliers or their capacities are rendered redundant. The firm needs to address this aspect through cost or revenue sharing approach. That is, a firm may part away with a portion of their profits when sales boom or share cost of increased production or decreased utilization of their business partners.

Lean

This approach was first introduced by Taiichi Ohno (1998) at Toyota Motor Corporation in Japan to eliminate wastes. He proposed automation and just-in-time (JIT) production as means to minimize inventory at all stages of production as inventory is construed to be a kind of waste. Womack (1991) in his book "The machine that changed the world" described how Toyota pioneered in lean implementation. This concept was further extended to downstream supply chain by Reichhart and Holweg (2007) to ensure supply of right product to the right customer at right time at right place. Vonderembse et al. (2006) proposed continuous improvement approach to eliminate waste or non-valued steps along the supply chain. They identified factors, namely, manufacturing efficiency and set up time reduction as enablers of economic production of low quantities, cost minimization, profitability and manufacturing flexibility.

Firms, in order to meet the volatile, uncertain, complex and ambiguous (VUCA) (Bennett & Lemoine, 2014.) market environment tend to build up redundancies in its supply chain. The assets and resources become redundant over the period of time. This results in sub-optimal utilization of these assets and resources (namely material, man and machine). Lean supply chain ensures that wastes, due under utilization of assets and resources; and non-value added activities, are minimized. Lean supply chains aim at level scheduling (Heijunka) to minimize waste (muda – the Japanese term)

Agile

The product life cycle is shortening over a period of time due to change in consumer preferences, innovations, health and environmental consciousness. Managing variety or variations calls for agility in supply chain. Change in product specification demands change in inputs and processes. An agile supply chain can only meet this challenge. The supply chain managers need to assess the agility of suppliers and production units to meet the response time and the changed specifications. Thus an agile supply chain has the ability to comprehend and respond to the customers' needs. It aims to address the volatility in variety, and some authors suggests that agility is also the ability to respond to change in demand volume (Agarwal et al., 2007; Christopher, 2000).

Agile supply chain focuses on building redundancies or reserving capacities to cope up with changing market needs (Christopher & Towill, 2000). Agility is proposed to be implemented through different means, such as:

- Integration of partners (Baramichai et al., 2007; Gunasekaran, et al.,2008));
- Supply chain structures and relationship configurations;
- The end-to-end visibility of information;
- The event driven and event-based management.

In case of innovative supply chains, agility is a challenge; and hence the decoupling point is required to be identified. It divides the supply chain into two segments, one that responds directly to the customers requirement and second, the part that uses forward planning and a buffer stock of inputs to make products. This helps in meeting the demand variability Naylor et al. (1999).

An agile leadership plays a crucial role in implementing agile supply chain in a volatile-uncertain-complex and ambiguous (VUCA) environment. The acronym, VUCA, was introduced by the US Army College to describe the dynamic environment (Bill Pasmore & CMC, 2010).. The distinct meanings of these elements are:

- **Volatile:** It refers to the nature, speed, volume, magnitude and dynamics of change;
- **Uncertainty:** It refers to the lack of predictability of issues and events;
- **Complexity:** It refers to the perplexing issues and disorder that surrounds the firm;
- **Ambiguous:** It refers to the fuzziness of reality and mixed meaning of conditions.

Resilient

Apart from shortening product life cycles and the existence of VUCA environment, supply chain can get disrupted due to force majeure causes such as natural calamities, war, strikes, civil commotion, political disagreements, act of terrorism, outbreak of epidemics and endemics and similar reasons. A resilient supply chain would mean the ability of a supply chain to recover from such disruptions, adapt to changed scenario, continue with business and even leverage such disruptions.

The firms in the process of getting leaner end up losing business at the time of unexpected disruptions (Azevedo et al., 2008; Peck, 2005) as they did not have additional capacities or alternative chains to fall back. A resilient supply chain should be able to restore the supply to its desired state within an acceptable time limit; and reduce the impact of disruption. Resilience also refers to the ability of a firm to anticipate and take preventive actions (Haimes, 2009).

Supply chains need to be resilient (Tang, 2006). There are different suggestions on the ways and means to be resilient. It includes:

- Design of a flexible and agile supply chain;
- Adoption of postponement strategy,
- Stakeholder empowerment; and
- Supplier diversity and relationship.

Green

Every business needs to be sustainable in long run. This means it takes care of people, profit and planet. Though all commercial ventures target profit, they tend to overlook people and planet. The deaths of drivers of Domino Pizza delivery persons and use of child labour in cobalt mining are the examples of lack of corporate social responsibilities. Use of materials that cause environmental pollution makes business unsustainable over period of time. A supply chain manager needs to inbuilt green concept and practices in design of products or services, sourcing of inputs, operationalization of processes, packaging, transportation and disposal of used and returned materials and goods. Gottberg et al., (2006) defined eco-design as way to develop durable and energy efficient products eliminating use of toxic materials and that can be recycled, if not re-used.

Supply chains are also affected by distribution and transportation operations network. In global supply chains goods move longer distances in ships causing higher fossil fuel consumption, and emission of carbon dioxide and other toxic gases (Sarkis, 2003; Venkat & Wakeland, 2006). Lean practices require lowering of inventory levels but this may lead to increase in number of deliveries for replenishment causing increase in emissions. Thus there may be a conflict between lean and green supply chains, especially in long distance deliveries (Carvalho, & Cruz-Machado, 2011). Studies show green supply chains can minimize impact on ecology, without affecting the quality, reliability, performance and cost; thus leading to overall economic profit. (Srivastava, 2007).

Implementing Sustainable Supply Chain Management

Supply chain practices need to be sustainable with regard to social, environmental and economic terms (people, planet and profit). Global reporting initiative (GRI, 2018) has laid down the framework to measure performance of a firm with respect to three dimensions of sustainability. GRI has laid down standards on management disclosure on their practices. It Includes:

GRI - 102: “Management contextual information and sustainability reporting practices”; and
GRI - 103: That deals with “ management reporting system on material topic
GRI – 200: Reporting on economic affairs

GRI -300: Reporting on environmental practices-; and
GRI-400: Reporting on social practices.

For example, GRI – 401 describes performance measure related to employees (a component of social dimension). These include disclosure by the management on "new employee hires and employee turnover (Disclosure 401 -1)"; " benefits provided to full time employees that are not provided to temporary or part-time employees (Disclosure 401 -2)" and "parental leave (Disclosure 401 -3)". GRI has even developed metric to measure firms' attitude towards employees regarding availing of parental leave. Two such measures are:

$$Return\ to\ Work\ rate = \left\{ \frac{\left[\begin{array}{l} Total\ number\ of\ employees\ retained\ 12\ months\ after \\ returning\ to\ work\ following\ a\ period\ of\ parental\ leave \end{array} \right]}{\left[Employees\ due\ to\ return\ to\ work\ after\ parental\ employee \right]} \right\} * 100$$

$$Employee\ Retention\ rate = \left\{ \frac{\left[Employees\ who\ returned\ to\ work\ after\ parental\ employee \right]}{\left[\begin{array}{l} Total\ number\ of\ employees\ returning\ from \\ parental\ leave\ in\ the\ prior\ reporting\ periods(s) \end{array} \right]} \right\} * 100$$

Similarly, it provides management framework for disclosure on water and effluents (GRI- 303), and occupational health and safety (GRI-403)

A synchromodal planning approach towards transport orders can aid simultaneous minimization of cost, delay and emissions (Mes & Iacob, 2016). A shipper may have different routes to select which differ in terms of time, cost and emission. He can select the route that not only meets the customers' delivery time requirement, at the lowest possible cost but also accounts for minimisation of emission levels. The emission levels vary amongst different modes of transportation namely, trucks, rail- electric, rail-diesel, and barges. The emissions are lowest in case of rail followed by barges; and are highest in case of trucks (Psaraftis & Kontovas, 2009; Cefic, 2011), In addition emission levels vary with time to deliver. Routes, which may appear shorter, may involve more emissions due to congestions, especially in case of road transportation.

Thus a supply chain needs to be FLARG (Flexible – Lean – Agile – Resilient – Green) compliant. Carvalho, & Cruz-Machado (2011) have proposed to integrate the paradigms of lean, agile, resilient and green supply chain. They put forward that while, leanness in supply chain reduces cost, hence maximizes profit, agility too maximizes profit through meeting the exact needs of customers. However, resilient supply chains look for enhancing their capabilities to cope with the uncertainty in business, this may lead to increase in cost; and at the same time supply chain need to address the concerns of environment to remain sustainable without just addressing the objective of minimizing the cost. Thus there is a need to trade-off between profits, lean, agile, resilient, green management and sustainability paradigms.

Supply Chain Planning

In terms of traditional concepts, planning involves three levels. These are the strategic planning, tactical and operational planning. In supply chain management strategic planning involves orientation of supply chain strategy with business strategy. It starts with the company's offerings to the customer in terms of form (packaging), place, time and price of the product. Table 1 illustrates the business – supply chain strategy matrix:

Push strategy refers to the firms' decision to supply goods and products based on demand forecasting. Pull strategy implies firms' decision to supply goods and products based on its actual demand. In case of cost-leadership strategy, the firm ensures availability at low cost through make-to-stock operational strategy. Here the firm maintains an inventory of products based

Table 1. Business: supply chain strategy matrix

<table>
<tr><th>Business Strategy</th><th>Supply Chain Strategy</th><th>Strategic Objectives</th><th>Strategic Planning</th></tr>
<tr><td>Cost Leadership</td><td>Push Strategy</td><td>Ensure availability of right product at lowest cost</td><td rowspan="3">I. Make or Buy Strategy
Outsource or carryout in-house: Design-Source-Make-Deliver-Return of components, products and services
II. Service Level
a. Response Time,
b. Technical, After-sales-service and Return strategy
III. Key Facilities and Location Strategy:
a. for Domestic Sales
b. as Exporting Firm
c. as Multi-national company
d. as Global firm</td></tr>
<tr><td>Product Differentiation</td><td>Push – Pull Strategy</td><td>Ensure availability of differentiated product at right cost</td></tr>
<tr><td>Focus</td><td>Pull strategy</td><td>Ensure availability of customized product at right cost</td></tr>
</table>

on demand forecasting and different service level objectives. This enables the firm to produce in bulk and lower its cost as it achieves economies-of-scale in production. This strategy is followed for functional products and components in manufacturing used prior to the decoupling point. The customer order decoupling point (DP) is defined as the stage or the point in the value chain for a product up to which a firm follows push strategy and waits or links further value addition based on customer order. It is also referred as order penetration point. An example of customer order decoupling point is shown in figure 11.

Figure 11. An illustration of a customer order decoupling point

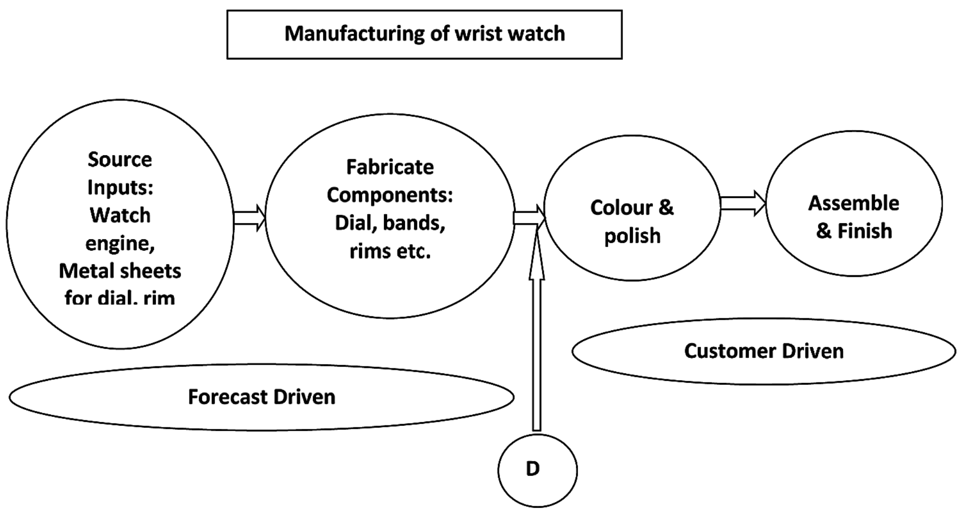


Table 2.

<table>
<tr><td>Decoupling Point (DP)</td><td colspan="2">Design</td><td colspan="2">Fabricate</td><td colspan="3">Assemble</td><td>Deliver</td></tr>
<tr><td>Build-to-stock</td><td colspan="6">Forecast Driven</td><td>DP</td><td>Customer Driven</td></tr>
<tr><td>Assemble-to-order</td><td colspan="3">Forecast Driven</td><td colspan="2">DP</td><td colspan="3">Customer Driven</td></tr>
<tr><td>Build-to-order</td><td colspan="2">Forecast Driven</td><td>DP</td><td colspan="5">Customer Driven</td></tr>
<tr><td>Engineer-to-order</td><td>DP</td><td colspan="7">Customer Driven</td></tr>
</table>

The decoupling point shift towards left in the value chain for innovative or differentiated products compared to functional product. Figure 12 illustrates the position of decoupling point in different operations strategy.

Make-to-stock refers to the push-strategy. In case of product differentiation strategy, the firm ensures availability of the desired type and model through make-to-order (or build-to-order) operational strategy. The operations under the category of assemble-to-order and build-to-order are referred to push-pull strategy. Engineer-to-order operations follows pull strategy.

Global Logistics Management

Logistics management deals with delivery of goods to the right entity at right place at right time at the right cost following the right practices. The delivery is ensured through the right logistics mix. The logistics mix has four elements, namely, the packaging, material handling, warehousing and transportation. These are the operational drivers and its integration is dependent on the customers' requirement (the last mile delivery) and the available modes of transportation. In global business, transportation is mostly multimodal in nature. This implies involvement of more than one more of transport and one node (terminals). The quality of multimodal transportation is affected by factors such as infrastructure, communication, capabilities of services providers, process and documentation. The responsibility of the seller with regard to multimodal movement varies in terms of international commercial (INCO) terms.

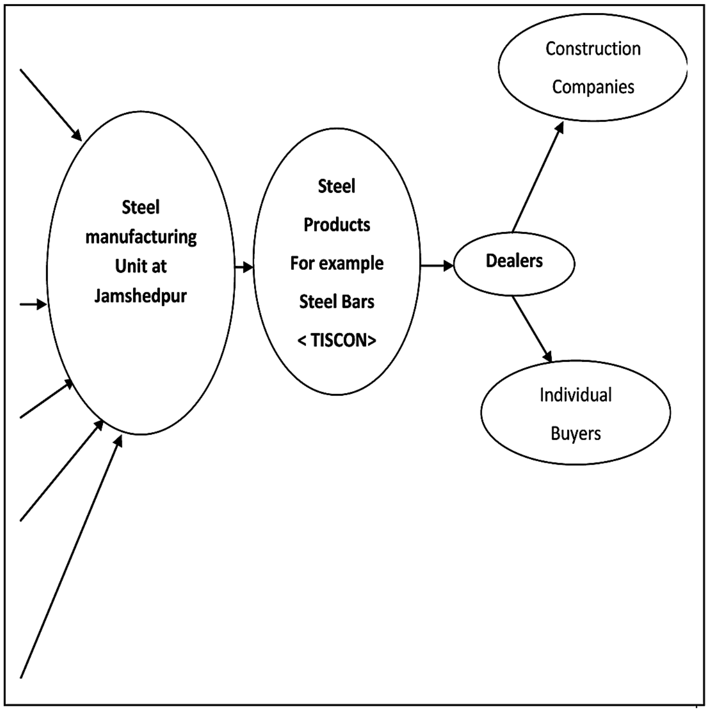
CASE STUDY

Example: Supply Chain of Tata Steel Limited – India Operations

Tata Steel has presence over 26 countries. It started from its India operation at Jamshedpur in the eastern part of the country with a capacity of 13 Million tons per annum (MTPA) as in 2018. It has presence in Europe as second largest steel producer in this economic union. In Europe it has capacity of 12.1 MTPA as in 2018. In South-east Asia it has operations in Singapore, Thailand and China. Figure 12 illustrates the supply chain network of Tata Steel Limited – India Operations

Figure 12. Supply chain of Tata Steel Limited (TSL)

INPUTS
Iron Ore: Own Captive mines at Noamundi, Joda, Khondbond and Katamati in the states of Jharkhand and Odisha.
Chromites: **Own Captive mines at** Sukinda Block of Jajapur district of Odisha
Coal: Own Captive mines at Jharia & West Bokaro, in the state of Jharkhand
Manganese Ore: Own Captive mines at Bamebari, Odisha
Dolomite: Own Captive mines Gomardih Dolomite Quarry



Tata Steel Company in India has under its hold the mines to supply iron ore and other minerals for manufacturing iron and steel, the rolling mills to produce steel, the steel bars from crude iron and steel. The Tata Group have their subsidiary logistics shipping company (TMIL) for managing shipments, their own ports and /or Berths in some of the ports to handle cargo. In a way, TSL has vertically integrated its logistics activities with entities under its own control.

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Chapter 2
Supply Chain Complexity

ABSTRACT

This chapter focusses on the concept, drivers, and perspectives of supply chain complexity of a firm. It discusses the impact of number of tiers, number of nodes in each tier, its links and flows on complexity of a firms' supply chain. This chapter tries to bring out the dynamic interactions between tiers and nodes. This chapter suggests that the levels of supply chain and its dynamic complexity are influenced by the products, processes, relationships, and the environment of the firm and its suppliers and distribution partners. Here the drivers, namely, the 5Vs (value, volume, variety, volatility, and visibility), 3Ps (process, people, and planet), and the global market (as a driver) that lead to complexity have been discussed. The complexity of supply chain has been explained from different perspectives. These are the system and process perspectives. This chapter introduces the concept of systems thinking proposed by Forrester and Senge. It illustrates the need to apply a holistic approach in reduction of supply chain complexity. The causality doctrine, proposed in this chapter, enables a supply chain manager to carry out policy experimentation. Supply chain structure varies across organisations. This suggests that a process framework along with application of systems thinking will aid supply chain managers to make supply chain less complex and lean. That is, the supply chain has the desired properties, namely, repeatability, testability, serviceability, flexibility, and cost efficiency. The next section

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talks about the importance of production processes in reducing complexity. Finally, the chapter discusses about the optimal number of suppliers a firm may have to meet its objectives. It argues that if past do not extend in future, the number of suppliers will add redundancy to the upstream supply chain, and at the same time, if future exceeds past, the supply chain fails. There are different options available to meet these challenges. These could be "buy-back" or "pay-back" or "rate contract" options. This chapter introduces the computational framework for assessing complexity of a firm based on its structure. This framework will help supply chain managers to carryout experimentation on the design of a supply chain network.

INTRODUCTION

A firm whether it decides to make or buy or do both, sources different inputs from its suppliers. This comprises the upstream supply chain of the firm. Similarly, the firm may decide to sell its products directly to the end customers or through a distribution channel, comprising, distributors or dealers and / or wholesalers and retailers. This constitutes the firms' downstream supply chain. Besides a firm may have its warehouses, production or assembly plants located at same or different places. This is firms' internal supply chain. This forms a network as shown in figure 1.

A firm can have multiplier tiers of suppliers, production centres and distributors. Each tier can comprise multiple supplier, internal operations and distributor respectively. Figure 2 represents a simple supply chain, where the firm has one supplier and one customer. The complexity increases with increase in suppliers, internal setups and distribution partners

The flow amongst the nodes representing suppliers, production centres and distributors can be multi-directional. There could be a situation where a supplier, say S_1, supplies material to the production centres, say, WIP_1 and WIP_3. Similarly there could more than one flow originating from any of these nodes to more than one node. Even there could be a direct flow from the supplier (of the firm) to the customer. For example, a battery manufacturer can supply to a mobile manufacturer and also supply directly the same to the distributor or end customer who wish to replace worn out batteries of used mobile phones. Figure 3 represents such as case.

Figure 1. An illustration of a supply chain network

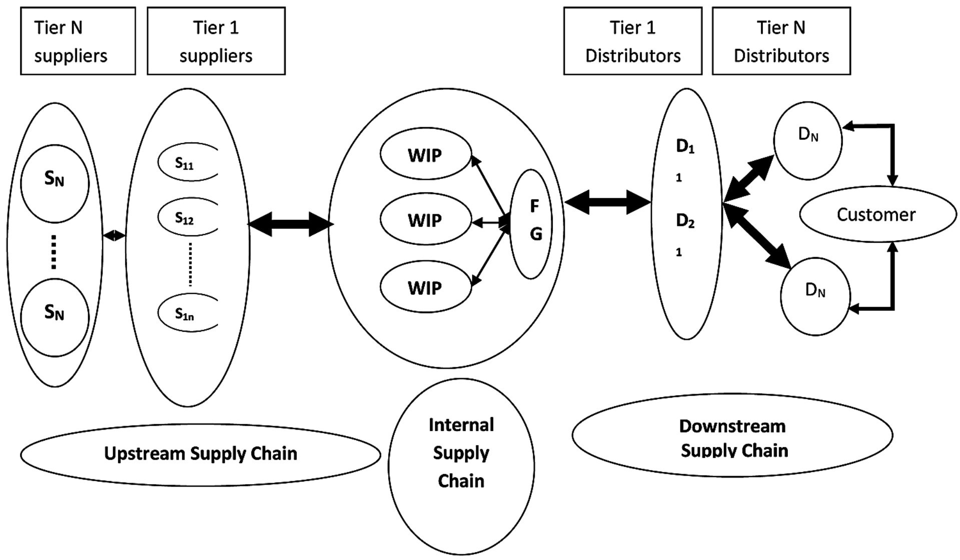
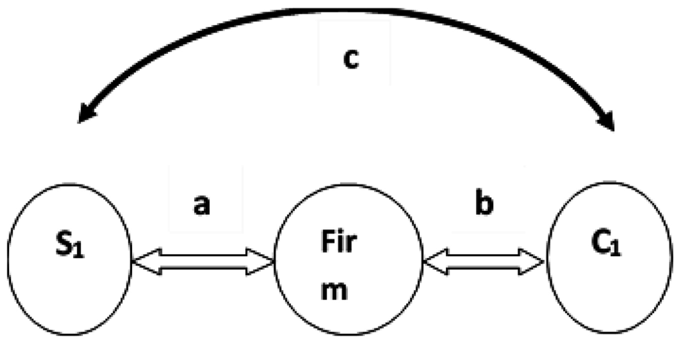


Figure 2. A simple supply chain

Figure 3 shows that supplier S_1 supplies not only to the firm but also to its customer. However, the flows, represented by a, b and c may not be under the control of the firm. Say the supplier supplies battery to the firm and sells directly to the customer. In that case, the flow "c" is not under the control of the firm. Whereas, if the firm on receipt of order for battery replacement directs its supplier to directly supply to the customer, has some responsibility for the flow "c"; as any deviation in customers' expectation will cause the customer to lodge a complaint to the firm and / or the affect the goodwill of the firm.

Supply chain complexity need to be studied from different perspectives. Some authors (Bozarth et al, 2009; Serdarsan, 2012) described complexity arising out of internal sources i.e., decisions on product and processes design; supply and demand interface. Complexity also arises out of flow of materials and information between the firm and its supplier and customers; and due to

Figure 3. Multiple flows from a particular node in a supply chain



the external drivers such as market volatility, government regulations and other environmental factors. Some authors (Vachon and Klassen, 2002) explain complexity in terms of the number of nodes / components and stages or tiers in the system; while Sivadasan et al., (2006) suggest that the complexity arises out of dynamic interactions between stages. The ***definition of complexity*** was well drafted by Bozarth et al. (2009), as – "the unpredictability of system's response to a given set of inputs". Complexity can be categorized as detail and dynamic complexity (Bozarth et al 2009); or static and dynamic complexity (SerdarAsan, 2013). Modrak, et al. (2015) provided an architectural framework suggesting supply chain complexity indicators based on Axiomatic Design theory and Boltzmann entropy.

Thus complexity of the supply chain of a firm increases with the number of tiers, number of nodes in each tier, its links and flows (or dynamic interactions between nodes).

STRATEGIC AND DYSFUNCTIONAL COMPLEXITY (AITKEN, ET.AL.2016)

The complexity of supply chain of a firm arises either out necessity (to meet the market needs) or out of improper planning. Thus complexity cannot be always viewed in negative terms. Different levels of customization and customers' varying requirements in terms of 5Rs (Right: Form, Place, Time Cost, and Practices) increases the complexity of firms' supply chain. This leads to increase in firms' supply base, in terms of number suppliers across different locations. This in turn leads to the introduction of multiple processes and relationships with suppliers. The relationships are established with different kinds of contract agreements with the supply chain partners. This is strategic complexity and not to be viewed as undesirable. Any change in structure (especially in terms of number of suppliers) may lead to drop in quality of supply chain. However, a firm over a period of time may operate under sub-optimal conditions with redundant suppliers in its network resulting in dysfunctional complexity.

A dysfunctional complexity does not add value to the firm and hence has an adverse effect on the firms' performance. In such a case, a firm may reduce its complexity, say, in its upstream supply chain, by reducing its supplier's base without affecting the performance. The efficiency or performance may even increase with this lean approach. The firm needs to establish the right type of contract and agreement with its suppliers. Harmonisation, standardisation and simplification of contracts are expected to reduce complexity.

Divers of Supply Chain Complexity

The 5Vs – Volume, Variety, Value, Volatility and Visibility; 3Ps – Process, People and Planet; and the geographical spread of firms' market act as drivers of complexity of supply chain. These factors lead to introduction of tiers (of suppliers and distributors), nodes in a tier (number of suppliers and distributors in each tier), the links between tiers and their relationships.

5Vs (Volume, Variety, Value, Volatility and Visibility): Drivers of Supply Chain Complexity

Volume or production size dictates the capacity requirement at supply level, firm level and distribution level. A single supplier and /or a production unit and /or a distribution point may not meet the market requirement. The firm need to optimize the supply chain keeping market needs and cost in view.

Variety or the extent of customization (or differentiation) makes supply chain complex. A firm have may have wide range of products to address different segments of customers. Say for example, Honda Cars has around 8 different models of cars. It starts from small car (Brio), hatch back (Jazz), low cost sedan (Amaze), mid cost sedan (Honda City), high end sedan (Honda Accord), and SUV range of cars (WRV, BRV and CRV). As the *variety* of product increases, the firm has to design exclusive supply chain for each of these types and make avenues for flexibility and agility in order to meet changing customers' needs.

Value to the customers is added when firm within a product or range of products offers multiple options in terms of size, functions, features and attributes, and packaging. For example, Honda car has 7 different range of offerings in their petrol version of Honda-City model, (namely, i-VTEC S, i-VTEC SV, i-VTEC CVT V, i-VTEC, i-VTEC CVT VX, i-VTEC CVT ZX, i-VTEC CVT ZX – Anniversary Version). Similarly there are multiple variants in diesel Honda-City cars.

Volume, variety and value commitment leads to complexity as the firm thrives to meet the multiple requirements to their customers. For example, the recent incidents of battery failures in leading mobile phone brands such as Samsung and Apple may have arisen out of the company's efforts to increase its value proposition in terms of long battery backup, reduced weight and so on. The suppliers of the firms could not meet the value proposition committed by the firms. Hence at one hand firms' endeavour to enhance value while on the other hand finding the right business partners is a matter of challenge to them.

Volatility in demand makes matter further complex. When demand increases the firms consider building buffers in inventory and production capacity, increases its supplier base and develops redundancies in the system. However, when the demand decreases all redundancies built by the firm adds to the list of nonperforming assets. This leads to closures, manpower retrenchments and shrinking of activities in a firm. Volatility arises out of change in consumer preferences, availability of substitutes, recession and economic slowdown. All these are not under the control of a firm. A firm needs to identify the controllable, uncontrollable and influence factors. Any internal decision is under the control of the firm, where as it cannot control the decision of its customers, suppliers and business partners; but may influence them with right offerings and contract agreements. Recessions, economic slowdown and government regulations can neither be controlled nor influenced. Firms may develop lead indicators to identify the potential threat in advance arising out of these un-controllable factors. Use of artificial intelligence based approaches may help developing such indicators.

Visibility refers to traceability of the components and products in a supply chain. This becomes complex when materials are sourced from global markets or finished goods are sold across borders. Global supply chain involves routing through multiple nodes across different countries with involvement of multiple stakeholders. Lack of visibility enhances the uncertainty and affects performance. This can be resolved by engaging capable third-part-logistics (3PL) service providers. The 3PL need to have multi-country presence with knowledge of political-economic-social-technological- legal and ecological (PESTLE) environment of the markets complemented with access to the right information technology.

3Ps (Process, People and Planet): Drivers of Supply Chain Complexity

Process

The processes followed by the firm are likely to influence complexity of the firm. Simple processes with less number of decision making units (DMUs) in each process, with automated tasks, standardized and simplified documents, transparent flow, defined accountability, distinct approving authority, well laid down escalation methods and grievance handling mechanism are expected to minimize the complexity of the supply chain. Complex and improper process mapping makes manageability complex. For example, a firm may follow a process illustrated in figure 4.

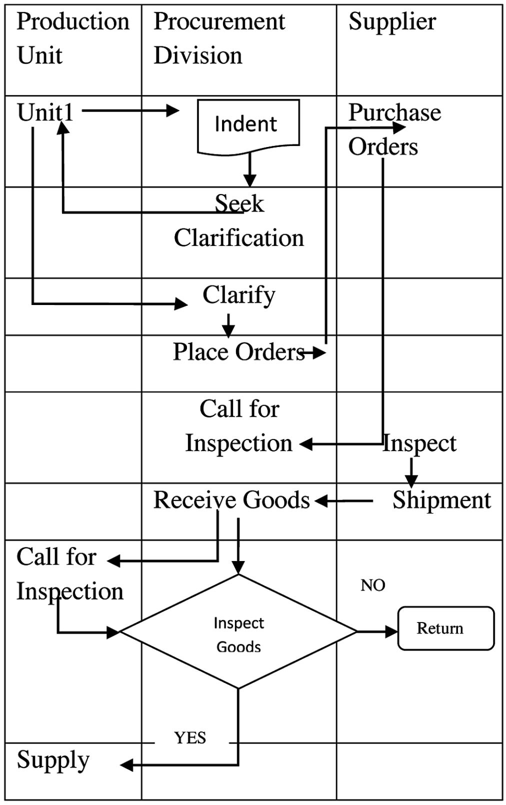
The above example demonstrates that there are number of non-value adding activities such as inspection. This activity does not add value to the customer. This also adds to the complexity, as the supply chain manager may have to look for alternate suppliers, if the inspection of products fails. Instead the firm may select and empanel those suppliers whose processes comply with their standards avoiding inspection at every stage. The firm may have quality controlled imbibed in the processes such that defects are minimized. A simplified process is illustrated in figure 5.

Figure 5 shows that the firm may carry out a supplier selection and empanelment process so as to enlist the right suppliers and do away with uncertainty in suppliers' performance and hence delete the non-value adding activities. This forms the pre-process to the procurement process of the firm.

People

The extent of specialization introduced in the operations and production process will call for different skill set to manage the process and its supplies. Manpower with multiple skill set coupled with automation reduces redundancies in their strength and makes operations manageable.

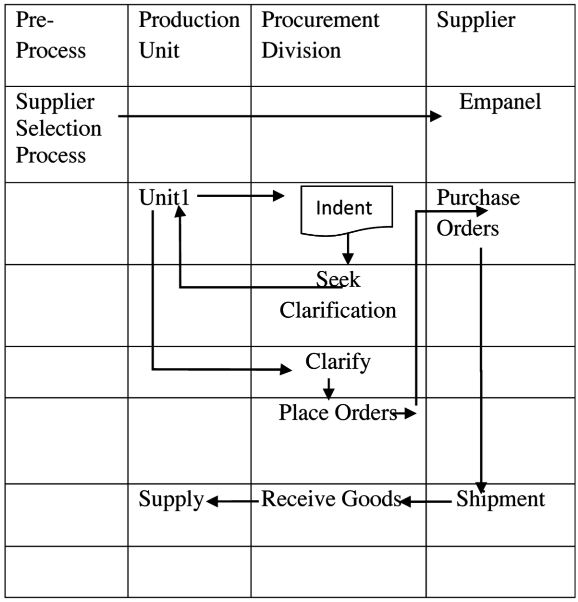
Figure 4. Process flow: An example



Planet

Environmental concerns and stringent statutes, for protecting the planet, introduced by different countries have led to the increase in complexity in supply chain of firms. For example, recent ban of diesel cars in Germany (https://www.express.co.uk/life-style/cars/930672/diesel-car-ban-Europe-Germany-fuel) has made the car manufacturers to rethink on their supply chain structures. They need to develop different supply chains for electric car and fuel variant cars. This makes supply chain complex as much of its operational parts are different. This is expected have domino effect in other countries in Europe. Countries such as UK have decided to ban diesel cars 2040 onward. Major car manufacturers are now uncertain and companies such as Volkswagen have declared that it would buy back the diesel cars, in Germany, when ban is finally implemented (https://in.reuters.com/article/germany-emissions-volkswagen/volkswagen-offers-to-buy-back-new-

Figure 5. Revised process flow: An illustration



diesels-if-bans-introduced-idINKBN1H51GK). Thus there is uncertainty and ambiguity in the supply chain of these firms.

GLOBAL MARKET: DRIVERS OF SUPPLY CHAIN COMPLEXITY

A firm may propose to sell their products across different countries. The complexity in global sale of products increases owing to - compliance with country regulations, tariff and non-tariff barriers; social and political risks.

For example, Boeing Aircraft manufacturers have formed an Environmental-Materials-Information-Technology (EMIT) consortium to facilitate product design and development in the context of meeting the environmental objectives and regulations. EMIT solutions are focussed on information and decisions relating to use of materials in the aircrafts and the processes followed by the manufacturing units. It develops software to enable mitigation of business risk, reduction of cost and compliance of country-legislations; benchmarking with best practices. This system has material datasets and facilitate design systems that are eco-friendly and critical. It allows innovation by the design teams, engineers and managers across the supply chain of the firm. It is collaborative effort between Boeing and its partners.

Different countries such as USA or EU have different regulatory requirements regarding use of materials especially those put under restrictive list. EU is governed by its REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) regulations while USA is governed by Dodd-Frank Act. Similar regulations exist for other countries too. The EMIT partners need to ensure that Boeing's products do not suffer from non-compliance; in addition, do not face a business risk due to material shortages and cost escalations. Otherwise this will lead to materials and / or processes being obsolete and expensive, as well.

Boeing sources materials from different countries and plans to mitigate the risk arising out of environmental and geo-political issues. Boeing does this by engaging positively with suppliers. The members of EMIT includes Airbus Helicopters, Boeing, Bombardier, Emerson Electric, Granta Design, Honeywell, NASA, NPL, Pratt & Whitney, Rolls-Royce, Sandia National Labs, US Army Research Labs, Source: Compiled From https://www.grantadesign.com/download/pdf/EMIT.pdf

PERSPECTIVES OF SUPPLY CHAIN COMPLEXITY

Systems Perspective

Supply chain complexity can be viewed from the systems perspective. This perspective calls for considering the supply chain holistically, describing it in terms of inter-related components; the interactions between components; and the behaviour exhibited by the system under the influence of the inter-component relationships, policy decisions and external environment. Peter M Senge (1992) introduced the concept of systems thinking to reinforce the causality doctrine proposed by J. W. Forrestor (1961, 1991). For example, when a node (say, a supplier) is deleted, the complexity reduces but may lead to increase in the time to respond to customers' orders. Forrester (1961) defines Industrial Dynamics as "…. the study of the information feedback characteristics of industrial activity to show how organizational structure, amplification (in policies), and time delays (in decision and actions) interact to influence the success of the enterprise. It treats the interactions between the flows of information, money, orders, materials, personnel, and capital equipment in a company, an industry, or a national economy". The system thinking on supply chain can be captured using System Dynamics approach. System Dynamics is a computer aided approach to understand the causality between the nodes affecting the rate and stock flows in a firm.

Figure 6 gives a context level illustration of systems approach to supply chain management.

Figure 6 illustrates that a firms' ability to deliver goods to customers is dependent on its suppliers. In case of failure, the customers are affected. Dissatisfied customers would shift loyalty affecting firms' production. This representation can be expanded to include the inventory, production rate, backlog and customers' satisfaction as shown in figure 7.

Figure 7 suggests that rate of production depends on existing inventory (on hand) of finished goods (FG), the desired level of inventory (the firm wishes to maintain) and inventory of inputs available with the firm. It implies that a firm at any given point of time *would like* to produce a quantity (of FG) equivalent to the difference between the desired level of FG inventory (it plans to maintain) and the existing inventory of goods. The desired level of inventory depends on the orders received (not shown as a link in the diagram, in order to keep it simple). However, *it can* produce the required quantity only when it has the supply of inputs. In this case, two suppliers supply the inputs to production. There are three direct links – a, c and h to rate of production. If any one of the links is disrupted, the rate of production is disturbed. Disruption for links "a" and "c" implies non-supply or incomplete supply by the two suppliers. Disruption of link "h" arises out of excess inventory held by the firm.

Assuming one supplier fails to supply; the production will be affected if the second supplier is unable to meet the additional requirement in the right time

Figure 6. Context level illustration of systems approach to supply chain management

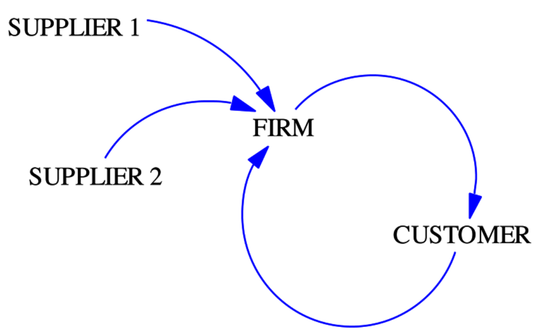
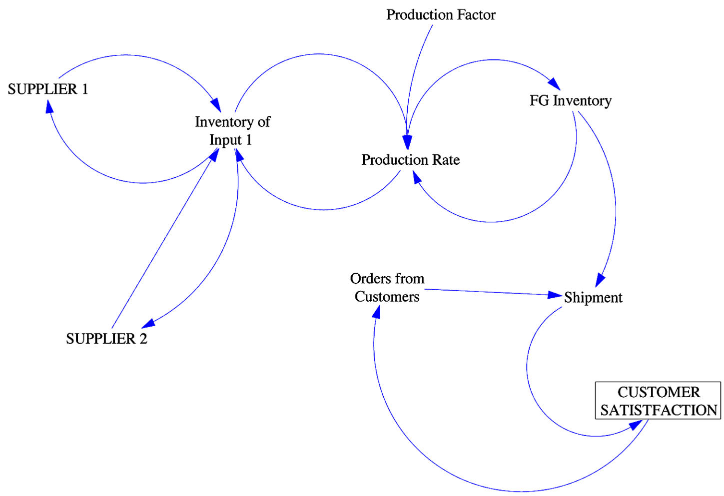


Figure 7. Supply chain links: A systems approach



at the right cost. In such a case the alternate supplier needs to be replaced with one meets such exigencies. Figure 7 illustrates that shipment to the customer is affected when the finished-goods inventory is less than the order quantity. Reduced or delayed shipment will affect customer satisfaction which in turn is likely to bring down the customer orders. When customer orders drop inventory turnover decreases resulting in increased cost and obsolescence.

The link “h” in figure 7 suggests that rate of production may suffer it the firm has unsold inventory of finished goods (FGs). This is turn will affect the suppliers’ rate of production. Varying rate of production is likely to cause uncertainty in suppliers’ business and hence discourage them to partner with firms with varying orders. In such cases, suppliers tend to exhibit inconsistent behaviour, hence complexity of supply chain increases. Thus complexity arises out of firms’ forecasting capabilities, inventory management, contracts and agreements between the firm and its supplier; and compatibility of strategic plans with tactical and operational plan. Many a times, lack of information sharing between supply chain partners in the downstream causes inventory accumulation in this part of the chain. This is called the bull-whip effect. This affects the flow from the upstream chain giving wrong signals to the suppliers. In such cases suppliers tend to shift their loyalty, become non-committal, and increase price of supplies. The firms may have no option but to explore and include other suppliers adding to the complexity in supply chain management. These counter impacts of firms’ supply chain uncertainty are denoted as link “b”, and “d” in figure 7. Inconsistent supplies will affect rate of production in long run leading to inadequate inventory (link "g"), this in turn will affect shipment (link "i"). Short shipment to the customers will have an adverse impact on customer's satisfaction ((link "j"), which may reduce orders (link "k") and hence affect the rate of shipment (link "l"). Figure 8 demonstrates the phenomena in form of a causal tree.

Finally the driver that drives business is the orders from customers. The flow of orders is affected by customer's satisfaction, illustrated in figure 9 below.

Thus, the system perspective enables us to understand the impact of disruption on any link, not only in the forward direction but also in the reverse direction altering the behaviour of the supply-chain system. A firm need to ensure a consistent behaviour arising out of its supply chain structure and avoid oscillatory behaviour that affects performance of the firm.

Process Perspective

A process is defined as a set of interrelated tasks performed to achieve a distinct business outcome. Supply chain management can be construed as management of set of processes associated with the upstream, internal and downstream supply chain. The processes can be centralized or decentralized or partly centralized and partly de-centralized. Lack of harmonized, standardized and simplified processes results in building up of redundancies in the supply chain. It all starts with the complexity in internal supply chain, followed by complexities set in due to wrong process and decision implementation across upstream and downstream supply chain.

Figure 8. The causal tree demonstrating cause and effect on shipment

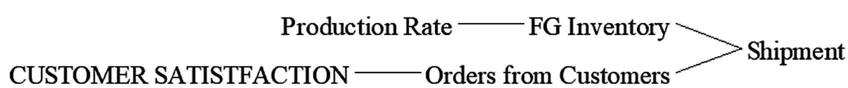
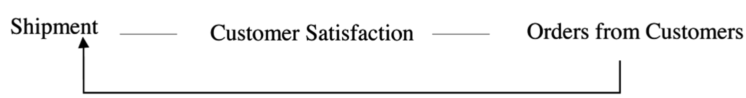


Figure 9. Causality between shipment and orders from customers



The supply chain planning process, as defined in SCOR model, developed by supply-Chain Council (SCC), includes 4 top level processes. These are plan, source, make, and deliver. It prescribes drill down of each of these top level processes into sub-processes.

The design of the product is one of the key factors in making a supply chain complex. Design decision relates to product structure (modular, integrated or any other combined structure), components, technology and processes (of manufacturing, after-sales-service, plant maintenance and disposal). The variety of components, their interconnectedness; and volatility in supply and cost makes a supply chain complex. Thus the complexity can be reduced by adopting a well-proven product planning process. This job involves research and development specialists, production and operation experts who integrate voice of customer (VoC), available technologies, risk involved, innovation and product life cycle elements into design of a product. Any shortcoming in planning process of new product development will have long term implications and cascading effect on upstream and downstream supply chain processes. Thus the supply chains need to have following properties:

1. **Repeatability:** The supply chain management of the firm should support repetition of production of products in the desired quantity, in order to meet customers' demand.
2. **Testability:** The firm should be able to identify and test the different components used in manufacturing the product. In case of any failure or poor performance, the firm should be able to identify the right part or component (through its performance testing) that caused such shortcomings.
3. **Serviceability:** In case of after-sales-service, the firm should be able to evaluate the performance of any single component or part, able to repair or service or replace the non-performing or underperforming component or the module constituting the product.
4. **Flexibility (in Volume of Production):** The supply chain management should support production of products in desired quantities and also the ability of the firm to ramp-up its production, demonstrating the characteristics of flexible supply chain.
5. **Cost (of Production) Efficiency:** The cost of production needs to be minimized without affecting the quality of the product. The direct cost, such as direct material, labour and others resources involved (e.g., equipment) can be tracked and need to be monitored to ensure containment of cost. The drivers of latent (or hidden) cost include the

types and numbers of parts or components, the technological changes required from time to time and the transportation cost of supplies. As the number of parts increases, more suppliers are required to ensure supply; hence the cost and complexity increases. Besides, different types of materials will require separate inventory management and controls. Many a time feedback from customers and service engineers leads to change in design and technology.

6. **Capabilities and Design Mapping:** The firm, when designs a new product needs to map its existing production facility with the requirements of its new product. The extent to which existing facilities, parts and components can be used in this new venture determines the resultant complexity in supply chain management of the firm. In case of new inputs, and changed manufacturing process, the firm needs to redesign and reorient its existing supply chain.

Example 1

Toyota recalled its cars produced between May 2000 and November 2001, and cars manufactured in the period April 2006 and December 2014 as they received complaints about defective air-bag (supplied by Takata). Toyota replaced the existing inflators (without drying agent) with new inflators (with drying agent), as the former had greater possibility of exploding.

Product Development Process

The product development process includes five stages, shown in figure 10.

Figure 10 shows a sequential development process. This is a bureaucratic approach where a stage starts only after completion of the previous stage. The feedback is restricted between two consecutive stages. Another approach, termed as *"concurrent engineering"* development process (figure 11), enables faster development with greater feedback opportunities (Bowonder and Miyake, 1993).

Figure 10. Product development stages

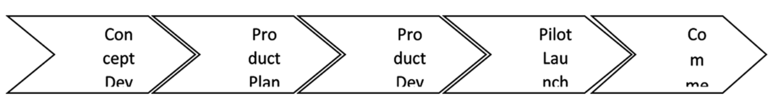
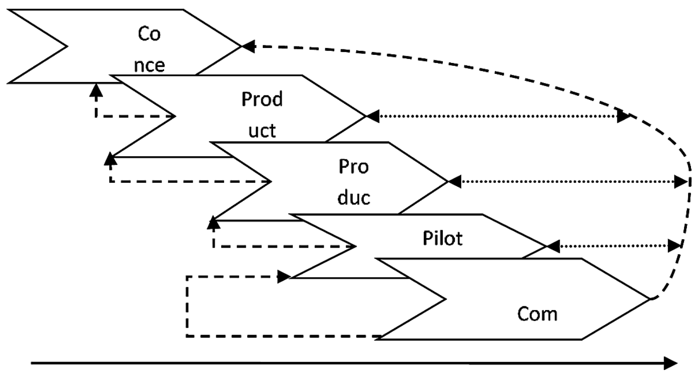


Figure 11. Concurrent engineering development process



[*Dashed lines indicate feedback between stages*]

Here there is an overlap between two consecutive stages. This approach is taken to speed up the development process, introduce feedback between various stages and early development of prototypes. Sequential development process is preferred when there is less agreement between marketing, finance, operations and supply chain on characteristics of products (such as functions, dimensions, features and other aspects). Otherwise, if there is a general agreement concurrent engineering is the best approach. The concerns and role of supply chain manager in the different stages is detailed below.

Product conceptualization and design will give rise to number of product models to be supported by the firm, and different internal components associated with it. Greater the number of components, higher is the complexity of the firms' internal supply chain. Subsequently, the production process (continuous, mass, batch, job or project) and the master scheduling of materials to meet the process requirement are the factors adding to the complexity. A supply chain manager responds to the production or operations manager by supplying the right material at right time and at right cost. He needs to trade-off between inventory and stock outs. The ideal situation is to ensure just-in-time (JIT) supplies at the lowest cost. Besides, he has to ensure that supplies meet environmental and social standards. A multitude of parts and components and divergence in technologies along the different product lines makes supply chain management complex. Hence, product planning process should look into the supply chain perspectives along with the other key aspects.

In the very first stage (*conceptualization stage*) the supply chain manager needs to assess the availability of suppliers; materials, other resources and technology; and capabilities to ensure success of new product development. In the product *planning stage*, the supply chain manager needs to assess the cost, the capabilities of suppliers and risk of procurement. In the next stage *(product development stage)* the supply chain manager needs to map the processes, decide on tiers, nodes per tier and the links (contracts and agreements) of supply chain. In *pilot-launch* stage, the supplies of input are ensured and trial supply chain operations tested and evaluated by the supply chain manager. Finally, all the activities in the previous stage should enable the firm to successfully launch their product in the market(s). The supply chain performance is reviewed at this stage and continuous improvement process initiated. In the long run several best practices are introduced. A mechanism to ensure that inbuilt errors do not go unnoticed, needs to be developed.. The supply chain manager may redesign its policies and network; continue to ensure high level performance of the supply chain.

The major supply chain processes include supplier selection and evaluation process; procurement and sourcing process; the warehousing and internal supply process; the distribution process and the return of goods process. The processes may be centralized or decentralized or a hybrid approach may be implemented. The advantage and disadvantages of centralized or decentralized planning is given in Table 1.

Supplier Selection and Evaluation Process

This involves the manner in which suppliers are selected, contracts and agreements made with the suppliers and the process of evaluating them. The first step involves screen of capable suppliers. A firm has to lay down pre-qualification criteria (PQC) to select suppliers. PQC includes expertise in manufacturing in terms of years of experience, number of clients, success stories and failure rates, quality and response time assurances. The selected suppliers are either empanelled for future supplies as per need or are awarded contract based on commercial and financial terms and conditions. There are different types of contracts, namely, one-time supply, rate contract (assuring supply for a period, usually a year at the fixed rate), buy back or payback contracts, contract manufacturing and different other forms.

Procurement Process

This involves the way requisitions from user divisions are received, forecasting, order placements, inspections, receipts, verification and issue of materials and inputs to the different units. Procurement is commonly divided under three categories, namely, stock items, non-stock items and exigent items. Low cost but fast moving items are normally considered as items to stock. High valued items are not generally stocked as it increases the holding cost. Exigent items are requirement not predicted earlier for procurement. A high frequency of procurement of exigent items is an indicator of poor procurement planning.

A procurement manager needs to have clear policies with regard to:

1. Scarce items
2. Import items
3. Restrictive item
4. Slow moving items
5. Very important and crucial items
6. Items with long lead time of supply.

All items should be green policy compliant.

Warehousing and Internal Supply Process

This involves the pickup, inspection, despatch of supplies to the production units and return of goods.

Distribution Process

This relates to the activities with respect to receiving orders from dealers and / or other direct customers of the frim (such as wholesalers or retailers), processing of orders, intimation to warehouse, packaging, booking of transportation, despatch and return of undelivered goods.

An incorrect or inefficient process will make manageability of supply chain complex. The decisions based on such process will affect the performance of supply chain. Each process needs to be formulated so as to retain the value added activities (VA), remove the non-value added activities (NVA) and minimize the effort and time of statutory or required non-value added activities (RNVA), such as filing of compliance statements to statutory bodies and similar activities. The processes need to be lean with time to perform each task matching the customers' expected response time and at the same time meet the volatility of demand and supply.

The Number of Suppliers: Decision Framework

Figure 12 suggests that number of suppliers depends on the production strategy on one end and the capacity of suppliers at other end.

The capacity is the ability of the supplier to produce and supply the desired quantity within the desired time. If a firm has productivity to produce "x" units per day, then its capacity in "y" days is "x*y" units. The variable "y" is the response time required by the firm. If the capacity "x*y" does not match the ordered quantity, then the number of suppliers needs to be increased. The response time (y) will depend on whether it is for "make-to-stock" items or "make-to-order" items.

In case of make-to-stock products, the value of "y" will depend on much stock the firms keep as buffer and how much it orders considering the lead time it can permit to a supplier. For example, a firm may decide to keep a buffer stock of 100 units and decides to order for 100 units within lead time of 20 days. If a supplier produces 1 unit in 2 days, its productivity is half unit per day (0.5 per day) and its capacity to produce in 20 days is 10 units (0.05 * 20). Thus, the number of suppliers required is equal to 10 (100 ÷ 10).

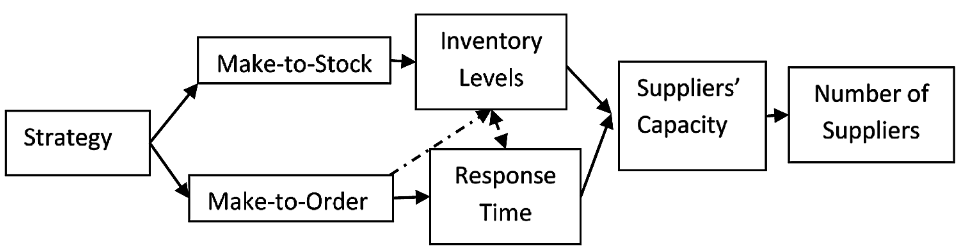
Mathematically, the above computation can be expressed as:

$$N = D \div (x*y)$$

where:

N = number of suppliers

Figure 12. Number of suppliers: a decision framework



D = Orders to be supplied in “y” days
y = Response or lead time stipulated by the firm
x = Supplier’s productivity per day

In case of “engineer-to-order” the firm may have less option to keep stock and quantity to be ordered for supplies are not fixed; in addition the time to supply may be more stringent. That is, “D” and “y” can vary and is not deterministic or certain as in case of “make-to-stock” strategy. The decision on number of suppliers needs to be based on probability theory. That is, the quantity to be ordered will be the expected value of demand, based on past sales. If past do not extend in future the number of suppliers will add redundancy to the upstream supply chain and at the same time, if future exceeds past, the supply chain fails. There are different options available to meet these challenges. These could be “buy-back” or “pay-back” or “rate contract” options.

Apple Inc. (US) has introduced “supplier diversity program” to meet its procurement challenges. Under this program it invites potential suppliers to get registered with Apple – Supplier – Connect in their website. Apple specifies its quality and other requirements and even empowers the potential suppliers to meet the standards set by them. The firms are required to participate in the Apple’s procurement process when there is a requirement. Registration of a firm does not guarantee of any orders to the registered suppliers. If no order is placed within 6 months of registration the firm needs to re-validate its information with Apple to continue remain registered. [Source: https://www.apple.com/procurement/]

Complexity Measurement Framework

Supply chains are network of multiple entities and act as complex adaptive system (Choi, Dooley & Rangtusanatham, 2001; Wysick, McKelvy & Hulsmann, 2008). These entities emerge over time into coherent form that exhibit adaptive actions in response to changes in both the environment and the system itself. In fact no one entity deliberately manages or controls it (Holland, 2002). The concept of complex adaptive system (CAS) suggests that a firm need to adapt to any change in the network. Adaptive natures such as self-organization, co-evolution, emergence etc. are the primary focus of this perspective. A causal model based on the principles of System Dynamics can help a manager to simulate the impact arising out of changes in network.

Chen-Yang Cheng et al., (2014) proposed an entropy model (based on Shannon's information theory) to quantify structural complexity of a supply chain system. The entropy measure associates uncertainty and complexity. It assumes that as a system grows in an uncertain environment, it becomes complex and hence requires additional information to understate state of the system and monitor it.

The entropy or in other words, the structural complexity is defined as:

$$H_s = -\sum_{I=1}^{n}\sum_{J=1}^{m} P_{ij} \log_2 P_{ij}$$

where:

H_s = Structural complexity
P_{ij} = Probability of resource I, I = 1,….n; in state j, j= 1, 2…..m
n= Number of resources
m = Number of possible states for resource i

For example, a material may have the following states:

1. Not yet Despatched
2. Despatched
3. Delivered

The variations in information and material flow can be described as:

Table 2 provides an illustration of data related to variation.

The structural complexity H_s can be computed as shown in table 3. It shows that the firm has a structural complexity of 1.79 against ideal score of 0.

Table 1.

Flow	Variation
Information	Confirmed date of despatch - Committed date of despatch
	Confirmed date of delivery - Committed date of delivery
Material	Actual date of despatch - Scheduled date of despatch
	Actual date of delivery - Scheduled date of delivery

Source: Adopted from Sivadasan et al. 1999)

Table 2. Computation of variation

Month	Target Order	Actual – Received	Variation
1	40	37	3
2	35	36	-1
3	31	31	0
4	40	38	2
5	42	46	-4
6	40	40	0
7	38	38	0
8	42	36	6
9	42	39	3
10	44	38	6
11	42	40	2
12	42	44	-2

Table 3. Computation of structural complexity - H_s

Scheduled - Actual Delivery				
States	**Variation Range**	**Frequency**	**Probability**	**H_s $-\sum\sum Pij\ Log_2 Pij$**
In control	0	3	0.25	0.00
Out-of-Control States	$0 \leq x \geq 2$	2	0.17	0.43
	$4 \leq x \geq 3$	2	0.17	0.43
	$6 \leq x \geq 5$	2	0.17	0.43
	$-4 \leq x \geq -1$	3	0.25	0.50
	SUM	12	1.00	1.79

Operational or Dynamic Complexity

This aspect of complexity aids in determining the operation behaviour of a supply chain. It is observed directly from the processes especially the way queues behave in terms of its length, variability and compositions. This in turn represents the amount of information required to define the state of the system. Operational complexity is connected with monitoring of planned and unplanned events (Calinescu et al. 2000). Frizelle and Woodcock (1995), defined operational complexity as:

$$H_o = -(1-P)\sum_{I=1}^{n}\sum_{J=1}^{m} P_{ij} \log_2 P_{ij}$$

where:

H_o = Structural complexity
P_{ij} = Probability of resource I, I = 1,….n; in state j, j= 1, 2…..m
n= Number of resources
m = Number of possible states for resource i
P = Probability of the system being in state of control
1-P = Probability of the system being in state of out-of-control

The operational complexity Ho can be computed as shown in Table 4. It shows that the firm has a structural complexity of 1.34 against ideal score of 0.

In Table 3, it can be seen that that all the states (out-of-control) are not defined on equal intervals. For example, the interval "$0 \leq x \geq 2$" has a width of 2, while the interval "$6 \leq x \geq 5$" has width of 1, yet these two intervals have probability of 0.17. As such the complexities in these two ranges are equal. In order to meet this deficiency Isik (2010) introduced the concept of deviation d_{ij} of different states from the expected state. The acceptable state has a variation equal to 0, the mid-value of every range, can be considered as the deviation d_{ij} from the expected value (of zero variation). He proposed the following expression to compute the complexities:

Table 4. Computation of operational complexity - Ho

Scheduled - Actual Delivery					
States	**Variation Range**	**Frequency**	**Probability**	**H_s $-\sum\sum Pij\ Log_2 Pij$**	**Ho $-(1-P)\sum\sum Pij\ Log_2 Pij$**
In control	0	3	0.25	0.00	0
Out-of-Control States	$0 \leq x \geq 2$	2	0.17	0.43	0.32
	$4 \leq x \geq 3$	2	0.17	0.43	0.32
	$6 \leq x \geq 5$	2	0.17	0.43	0.32
	$-4 \leq x \geq -1$	3	0.25	0.50	0.38
	SUM	12	1.00	1.79	1.34

Note: Probability of success or state of "in-control" (P) is 0.25
Probability of out-of-control (1-P) is 0.75

$$H_s = -\sum_{I=1}^{n}\sum_{J=1}^{m}(\log_2 P_{ij})d_{ij}$$

where:

H_o = Structural complexity
P_{ij} = Probability of resource I, I = 1,….n; in state j, j= 1, 2…..m
n= Number of resources
m = Number of possible states for resource i
d_{ij} = Deviation from in-control state

$$H_o = -(1-P)\sum_{I=1}^{n}\sum_{J=1}^{m}P_{ij}(\log_2 P_{ij})d_{ij}$$

where:

H_o = Structural complexity
P_{ij} = Probability of resource I, I = 1,….n; in state j, j= 1, 2…..m
n= Number of resources
m = Number of possible states for resource i
P = Probability of the system being in state of control
1-P = Probability of the system being in state of out-of-control
d_{ij} = Deviation from in-control state

Table 5 shows the complexity results computed considering the deviation d_{ij}

Structural Complexity in Assembly Supply Chain (ASC)

In an assembly supply chain the processing are done in stages, where output of one stage (excepting the first stage) is input to the next stage. For every stage there may be more than one input supplier.

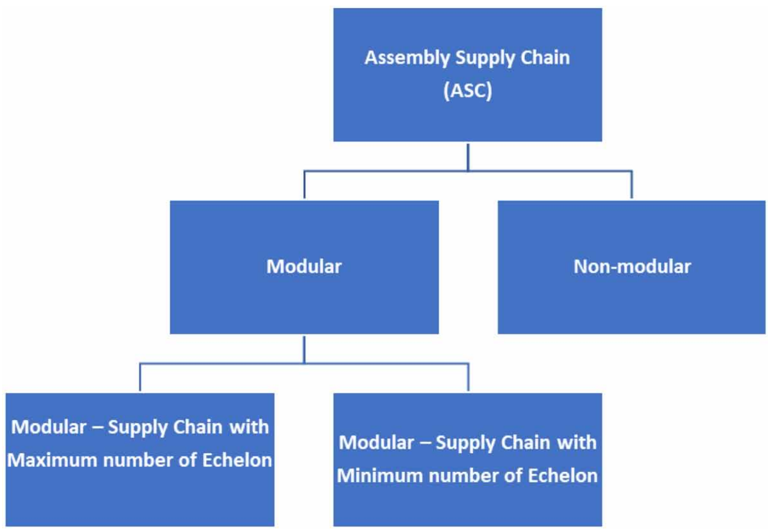
ASC can be categorized as modular or non-modular as shown in figure 13.

Figure 14 describes a mixed-model (of non-modular and modular) assembly supply chain.

Table 5. Complexity results computed considering the deviation d_{ij}

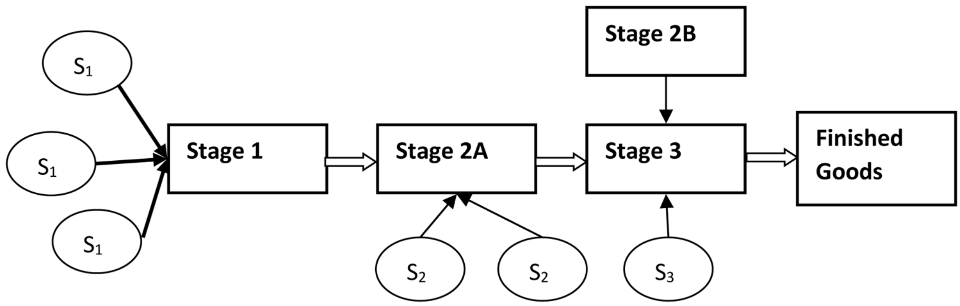
Scheduled - Actual Delivery						Isik (2010) Approach		
States	Variation Range	frequency	Probability	H_s $-\sum\sum Pij\ Log_2 Pij$	Ho $-(1-P)\sum\sum Pij\ Log_2 Pij$	dij Absolute value (Lower Limit + Upper Limit) ÷ 2	H_s $-\sum\sum Pij\ (Log_2 Pij)\ d_{ij}$	Ho $-(1-P)\sum\sum Pij\ (Log_2 Pij)\ dij$
In control	**0**	**3**	**0.25**	**0.00**	0	0	0.00	0.00
Out-of-Control States	**0 ≤ x ≥ 2**	**2**	**0.17**	**0.43**	**0.32**	1	0.43	0.32
	4 ≤ x ≥ 3	**2**	**0.17**	**0.43**	**0.32**	3.5	1.51	1.13
	6 ≤ x ≥ 5	**2**	**0.17**	**0.43**	**0.32**	5.5	2.37	1.78
	-4 ≤ x ≥ -1	**3**	**0.25**	**0.50**	**0.38**	2.5	1.25	0.94
	SUM	**12**	**1.00**	**1.79**	**1.34**		**5.56**	**4.17**
		Note: Probability of success or state of "in-control" (P) is 0.25						
		Probability of out-of-control (1-P) is 0.75						

Figure 13.



There are other possible configurations of an ASC. Figure 14 shows that the complexity in such a supply chain arises out of links within stages and due to transfer of complexity from one stage to another. Hence, there is stage level complexity and transfer or structure complexity. Thus ASC complexity is defined as (Hu et al. 2008)

Figure 14. Assembly supply chain: Illustration



$$C_{ASC} = f\left(C_s\right) + C_{st}$$

where

C_{ASC}: Complexity of ASC
$f(C_s)$: Function of - Stage or Station level Complexity
C_{st}: Structure level Complexity arising out of number links between stages.

$$f(C_s) = \sum_{l=1}^{K} H_s^l$$

where L = 1, 2…K Stages or stations

For each stage, the structural complexity is $H^K{}_s$

$$H_s^K = -\sum_{I=1}^{n}\sum_{J=1}^{m} P_{ij}(\log_2 P_{ij})d_{ij}$$

For example, there are 4 stages in ASC described in Figure 15.

The structural complexity of Stage 1 can be described as:

$$H_s^l = -\sum_{I=1}^{n}\sum_{J=1}^{m} P_{ij}(\log_2 P_{ij})d_{ij}$$

where

i = 1, 2 & 3 (inputs from S_{11}, S_{12}, S_{13})
j = States of each input i. There can be say 2 states (j =1: Despatched; j =2: Delivered)

Similarly, H^2_s, H^3_s, and H^4_s can be represented. Data on each stage and states in each stage need to be collected, and variation identified to determine the out-of-control states as illustrated in Table 4 above. Summation of H_s of all four stages will give $f(C_s)$.

The complexity arising out transfer from one stage to another C_{st}, is determined as:

$\log_2 (N_L)$

where;

N_L is the number of links (amongst the stages) in the assembly.

In Figure 14 there are 4 links. Hence; $C_{st} = \log_2(4)$

Since several different configurations are possible, the complexity for each configuration can be computed and one with minimum complexity can be chosen as the best possible supply chain configuration.

Additional Measures of Complexity (Modrak, & Marton, 2012)

Modrak, & Marton, 2012 suggested three metrics, namely, Modified Flow Complexity (MFC), Index of Vertex Degree (I_{vd}), Supply Chain Length (SCL) and

Modified Flow Complexity (MFC)

$MFC = \alpha.\ T + \beta.N + \gamma.L$

where

α, β, γ are weights to
T = Number of Tiers
N =. Number of Nodes

L = Number of Links; respectively.

α = MTI = (TN- N) / [(T – 1).N]

β = MTR = TN / N

γ = MLR = LK / L

where:

N = Number of Nodes
TN = Number of Nodes per i- th Tier Level
L = Number of Links
LK = Number of Links per i- th Tier Level
T = Number of Tiers

Index of Vertex Degree (I_{vd})

This index is used to measure the supply chain complexity from information flow point of view in different classes of ASC structure and is derived from Shannon's information theory. This is described as:

Example for Calculating Degree or Weight of a Node or Vertex

The computation for a ASC of the type given in figure 16.

Figure 15.
Where, V= Vertex/Node in a network and $deg(v)_I$ is weight of ith Node/Vertex.

$$I_{wt} = \sum_{i=1}^{V} \deg(v)_1 \log_2 \deg(v)_V$$

Figure 16. An illustration of a ASC
Tier-1: All Nodes the deg(v) = 0;
Tier-2: Node1, the deg(v)=3
Node2, the deg(v)=4
Tier-3: deg(v)=3
Tier-4:deg(v)=2

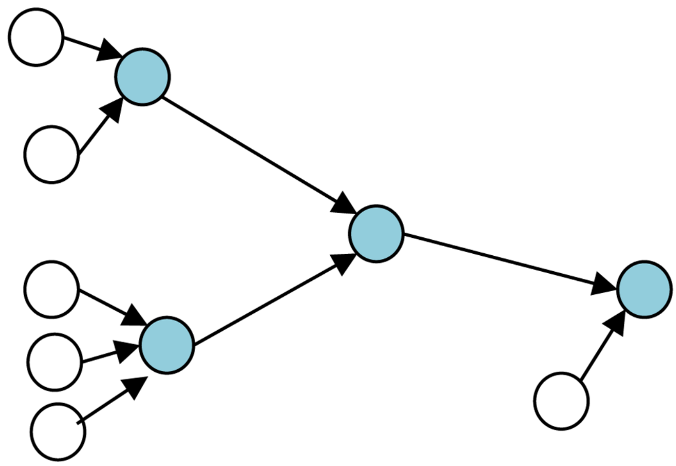


Figure 17.

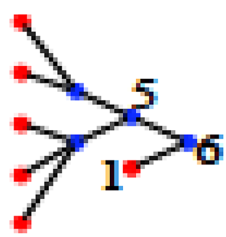


Table 6.

N	L	T	TN	LK	deg(v)$_i$			ivd
10	9	4	10	9	2	3	4	14.75

Supply Chain Length (LSC)

Supply Chain Length indicator, as defined byNemeth and Foldesi (2009), considers the number of nodes and links between the nodes as well. The links are weighted by its complexity. It is expressed as:

$$LSC = c_1 \sum w_s V_i + c_2 \sum_{(i,j)\in P} f(D_{ij}) \cdot A_{ij}$$

where:

c_1, c_2 are coefficients representing the technical and managerial level of vertices and edges;
w_s is the weight of node;
P is the path between origin and destination;
V_i represents vertices (nodes) in the path;
$f(D_{ij})$ refers to weight determined by the logistics distance
A_{ij} represents links or Arcs in the path;

A comparison by the authors shows that I_{vd} best describes the complexity of the network as a whole.

Modrak, Marton, & Bednar, S. (2013) introduced another indicator - Link/Tiers Index (LTI). This index is used to measure structural complexity of a network when we want to compare two or more structures with the same number of links "L" and nodes "N" but with different numbers of tiers "T". This is calculated by using the formula

$$LTI = \sum_{j=1}^{p} \sum_{k=1}^{m} LjTk0.1 \tag{4}$$

Example: In a class of ASC structure, there are two combinations where links "L" and nodes "N" are same but with numbers of tiers "T" is different.

See Figure 18 for Example 1.

Figure 18.
Here, T=3, N=8, L=7; Thus LTI= 2.1

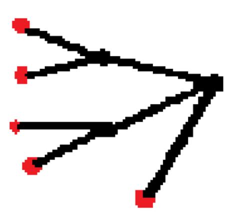


Figure 19.
Here, T=4, N=8, L=7; Thus LTI= 2.8

See Figure 19 for Example 2.

From the above examples we see that the structures which have less number of tiers are topologically less complex than the structure with more number of tiers.

The LTI Index indicates that the structures which have less number of tiers and links are less complex in nature.

The comparison can be summarized as:

- LTI is a suitable indicator for assessment of divergence of the same ASC structure class,
- MFC indicator is in comparison with LTI more suitable for comparison of different ASC structure classes
- Ivd has got an analogical advantage like MFC indicator against LTI, but seems to be more suitable than MFC because of the smaller variance of values in the appropriate ASC structure class.

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Chapter 3
Supply Chain Strategy

ABSTRACT

This chapter discusses the relevance, dimensions, and types of supply chain strategies. It puts forward the key aspect, that is, the supply chain strategy needs to be in line with the firms' business strategy or else the relevance is lost. This chapter relates the supply chain strategy with business strategy as whether a supply chain needs to be cost-efficient or responsive or how to optimize both cost and response time in view of its business strategy, whether to make or buy a product, how to relate supply chain with product and supplier life cycle, and whether the firm needs to pursue push or pull or a dual strategy.

RELEVANCE OF SUPPLY CHAIN STRATEGY

Supply chain strategy is derived out of the business strategy pursued by the firm. A firm may emphasise on low cost or differentiation or focus strategy to remain competitive. The supply chain strategy needs to be aligned with the business strategy. The firm has to decide whether the supply chain strategy will be "supply-to-stock" or "supply-to-order". In the first case the firm aims at low cost through bulk procurement and bulk movement (logistics); while in latter cases the firm aims at adapting the changing needs of the customer, i.e., pursue build-to-order and not build-to-stock strategy. It tries to be responsive rather being cost efficient. In a highly competitive market, firms selling similar products, compete on the strength of their supply chains.

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It is so because supply chain strategy impacts the revenue position, working capital and fixed capital efficiency; and the operating cost.

Bowersox et, al. (2000) identified 10 significant dimensions of change relevant to supply chain logistics value creation for firms The authors suggested that firms need to understand the value proposition sought by the customer instead of just addressing the fill-rates or on-time delivery. It needs to ensure the right way to address customers' need (that is, 5Rs- right form (dimensions, packaging, labelling and other delivery specifications), right time, and right place, following right practices at the right price). The firm need to build customer relationship by continually addressing varying needs (i.e., customizing 5 Rs for a particular customer). That is, they suggested a shift from *customer service to relationship management*. Firms need to treat their suppliers as partners and not vendors, meaning, they need to carry out collaborative planning, forecasting and replenishment (CPFR) including sharing of risk and benefits. The sharing should be made formal by the way awards and penalties are apportioned between the firm and its supplier; including these aspects in contract agreements. In short, the authors suggested shift from *adversarial to collaborative* supply chain management.

CPFR leads to shift from *forecast to endcast*. This means that planning should be based on end-to-end requirement instead of individual entities predicting their requirements in silos. This happens when firms *hoard information instead of sharing it through collaboration*. Forecasting gets biased with past data or information, it may to recognize the change in trends in initial stages (i.e. in transition stage) and detect the same at a stage when the firms lose their competitiveness. Hence collaboration will help to look into the future through eyes of different stakeholders. This situation require managers to understand the concept of the new beginning and may significantly vary from past. Hence a shift from *experience to transition* is required to remain competitive.

Firms tend to increase their gross sales, say in US Dollars, to reflect their market share, but may fail to recognize the reduction in marginal profit due to increase in cost of operations. Hence there is a need to shift from gross or *absolute to relative value*. Firms need not only to increase sale but also reduce cost by adopting efficient processes. Processes can be efficient if they are integrated end-to-end. Firms stress integration of their functional units but have limited integration with the entire supply chain processes that affect the inward, internal and outward legs of the supply chain. Hence there is a need for process integration that cuts across different external nodes, internal units and functions, logistics and other links that makes a supply chain of a firm. Traditionally many firms, such as Ford, prescribed vertical integration to ensure integration of the processes and exercise control over the same. However, in todays' world things are getting more specialized and even knowledge processes are outsourced, such as design and information processing. In these conditions firms need to shift from *vertical to virtual integration*, where in a firm creates a web of stakeholders having compatible vision and goals to remain focussed on core competencies. Hence knowledge of process is important.

Conventionally, companies focussed on development of skills and functions of an individual, while the need is for understanding the process as a whole; the risk, benefits and the winning formula. That is, training approach should focus on processes to enhance knowledge that integrate across different functional areas and multiple technologies. Thus there is a shift from *training to knowledge based learning*.

Low Cost Business Strategy

In this case firms aim at achieving competitiveness through cost reduction. For example, Wal Mart positions their sale in terms of low price they offer on a continuous basis. They introduced the concept of "Every Day Low Price" (EDLP) to attract consumers on a regular basis. Some companies such as Kmart or Pantaloons on other hand would offer discounts during specific periods or seasons when they offer special discount and attract customers on the basis of low cost. These strategies aim at two types of cost conscious consumers, namely, expected-price-shoppers and cherry-pickers. EDLP is aimed at "expected price shoppers" who prefer to buy from stores or retailers offering a low price, compared to others, on a regular basis. They do not prefer to stock or make bulk purchases. On the other hand, Kmart target price-vigilant consumers, also termed as cherry pickers. These consumers do pre-purchase surveys to find out the discounts offered by the retail stores and the season when discounts are high. They would stockpile their requirements during period of discounted sales. EDLP pursuing firms bring down their cost by reducing advertisement cost of offering seasonal sales and bulk purchases. The first tactics is quite simple to understand as the firms don't need to undertake such expenses, the latter tactics has a different implications. Bulk purchases on one hand lowers procurement cost while on other hand increases the holding cost, and if unsold will result in losses. Thus an accurate forecast and effective supply chain will enable to meet this objective.

An effective supply chain management will enable right stocking and avoid stock outs or obsolescence. The firms that prescribe to promotional schemes such as offering discounts operate on the high-low margin criteria. For every product they initially price them with upper limit of the profit margin and then push their sale offering discounts, i.e. selling at the low-margin. During this period the firms expect push in their sales; and their purchases and their shipments are, therefore, in bulk; thus taking cost advantage.

The operational supply chain strategy of firms pursuing low cost strategy can be summed as *"the firms aim at supply-to-stock strategy"*. That is, the firms make bulk purchases or do bulk production and carry out bulk shipment, as these leads to cost reduction. Bulk purchase will require assessment of - sourcing capacity of suppliers; level of inventory to be maintained; and determination of load per shipment. A full container load or full truck load or full car load or full ship load will entail lower cost compared to less carrier load or less container load. This implies that the firms should have sources to supply full carrier load cargo. At the same time the full carrier or car load cargo should match the economic order quantity or the optimal inventory level. A firm cannot procure more than its optimal requirement for the sake of attaining full carrier load cargo; there may be requirement of fractional shipment as well. Thus this involves multi-criteria decision making (MCDM).

The risk associated with such bulk production or purchase of finished goods is that with unsold amount (within the given shelf) life due to certain external factors such as government regulations or rumours of inadequate quality or impurity or presence of certain constituents that may cause health problems. This is true specifically with perishable items such as food items. For example, in May 2015, Indian Food Inspectors, banned sale of 2-minute Maggie noodles in India on the basis of reports indicating presence of certain constituent such as lead in the product. This led to piling up the unsold product in the retail stores. Nestle, the maker of this product recalled and destroyed the same. The retail outlets who could return the material suffered loses. *Thus, an appropriate recall strategy*, *as a tactical strategy, is needed to mitigate this risk.*

The firms pursuing supply-to-order strategy need to identify the suppliers in terms of capacity to supply desired quantity to meet the bulk requirement. In cases where a single supplier is unable to meet the quantity requirement, the firm need to have multiple suppliers. This implies that multiple contracts for a single product or stock-keeping-unit (SKU) are required to be managed by the firm. The major challenge lies with scarcely available materials. For example, suppliers of metals such as lithium and cobalt (used in batteries for electric vehicles) have limited capacities. With the increase in manufacturing of electric cars, the price of lithium has been increased manifold in 2018 and the trend is expected to continue. It is predicted that the demand for lithium for chargeable batteries would increase from around 93 thousand metric ton in 2017 to around 213 thousand metric tonne in 2025, as projected by Statista (2018). Lithium constitutes only 2% of an electric battery but becomes critical to production. The supply chain managers of electric vehicle manufacturers need to address the price and supply volatility issues. The firms have to find ways and means to ensure steady supply by entering into long term contracts, if required, with suppliers' to meet the targets. There may be a need to invest in suppliers' setup as well. In extreme situation, firms may think of identifying substitutes through research and development that is time consuming and a costly affair. For example, it took almost 50 years to substitute the lead-acid battery with lithium ion battery. Hence substituting lithium may be a difficult but may not be an infeasible option.

Case of Tesla Motors: June 2018

Tesla, a leading electric vehicle maker could not meet the production goal of its Tesla Model 3 car. The major reason was production of its battery module due to less availability of lithium. Tesla aims to invest in lithium mining companies to secure a steady supply of the metal. It has been negotiating with Chilean firm SQM as the closest suppliers to Tesla. Supply countries include the 3 Latin American countries, namely Argentina, Chile and Brazil.

Source: http://www.autonews.com/article/20180212/OEM01/180219948/tesla-lithium-ion-battery-supply, accessed on 03.07.2018.

Thus, the supply chain strategy for make-to-stock items *would be to design a "cost-efficient supply chain"*. The activities range from "identification of suppliers with adequate capacity"; to "investments in such companies to lower cost and ensure steady supply" ; "even innovate or look for alternative inputs"; "adopt the right contract" and "optimize the logistics functions". The strategy to procure material based on forecast is termed as push strategy.

Differentiation Strategy

Firms pursuing this strategy offer different range of products and or service that are unique compared to their competitors. These firms survive by providing superior value to the customer. It may also involve customization or tailoring on arrival of customers. For example, paint companies such as Asian Paints, a leading paint producing company in India, offer customization (i.e., to experiment with different colours) to suit their choice just before placing orders. Similarly, the leading Indo-Japanese car maker, Maruti Suzuki, offers 90 different customization kits under their "iCreate" personalization program. The major issue with these firms is uncertainty over the type of product (and or service) preferred by the customers at the time of purchase. Customers are dissatisfied if their choice is not available or there is delay in supply. The firm needs to postpone finalisation of operations till actual demand is known. In such a situation the firms cannot opt for "supply-to-stock" for items which are customer - driven. Here, the firms need to pursue "supply-to-order" strategy. For customer driven items bulk procurement may not be feasible and cost reduction on this account may not be achievable. The firm has to ensure that the required supplies are met within the stipulated response time of the customer. That is, firms aim at *"response-to-order"* strategy. Procurement based on customer demand is also termed as pull strategy. Thus, the firm has to partner with *responsive suppliers* to meet the dynamic requirement within the stipulated response time.

The supply manager has to ensure *flow of timely and correct information* from the downstream supply chain nodes (customer-retailer-distributor-wholesalers) to the upstream nodes (i.e. the suppliers. Many firms have ensured flow of their point-of-sale (POS) information to the suppliers simultaneously with other units of the firm.

Hence, the supply chain strategy of firms pursuing "differentiation" business strategy would be to develop and maintain a responsive supply chain. As tactical strategy, the firm may build relationship with their business partners. The contract with the supplier would depend on the availability of materials, criticality of the input to the product, volatility in demand, design and price. The supplying firm needs to be flexible (in meeting varying order quantities) and agile (in meeting varying specifications)(Lee, 2002)

Focus Strategy

A firm following focus strategy focuses on a particular market, customer or product mix. It can be low-cost-focus strategy or differentiation-focus strategy. For example, companies making products for persons with sight disabilities. There are specific manufacturers of braille and other products for visually impaired, such as Shadows in Dark (manufacturers of braille cards – playing cards, business or gift cards for blind and visually impaired), Freedom Scientific (manufacturers of computers and printers for the people with low vision or blindness), Tieman BV Holland (CCTV manufacturers) and similar firms. These firms face issues related to low sale; and in certain cases operate below economies-of-scale. These firms have to deal with niche inputs (components), technology and craftsmanship. The firm may have limited options for its supplies. If the product is highly specialized, the firm may need to develop its own expertise or have long term contracts with exclusive suppliers.

Another example could be that of *"design-to-order"* or *"design-to-order",* say, house construction companies specializing in customized houses. For example, companies such as Watts Homes & Construction construct homes of newer designs and houses made of non-conventional material, such as combination of wood, tent-cloth and / or brick and mortar. In such cases, firms face uncertainty regarding consumer preference and have may not have the option to stock even the basic inputs such as brick and mortar. Hence, operations may not achieve economies-of-scale. Here the decoupling point is located at the design stage (Gosling & Naim, 2009). In these cases, *firms may need to have pool of design specialists, strong research and development (R&D) team and a broad base of (empanelled) suppliers to meet the timely supply of the desired materials.*

Figure 1. Operations cycle

Table 1. Make or buy options

Stages	Make or Buy	Options
Plan a product	Make	Firm plans in-house – type and design of the product and its mode of operation
	Buy	Firm imitates prevailing products in the market and chooses to reproduce them to meet the growing demand
Design	Make	Firm carries out its research and development and designs the product and mode of operation
	Buy	Firm engages a third party to design the product for them
Inputs	Make	Firm decides to own its resources, process, fabricate and consumes
	Buy	Firm decides to buy the inputs to production
Assemble	Make	Firms uses the inputs to assemble the components that constitutes the product
	Buy	Firm outsources its assembly of components to a third party
Manufacture	Make	Firm produces the final product, packages and creates the SKUs (stock keeping Units) of final product
	Buy	Firm buys the final product from others instead of manufacturing it
Distribute	Make	Firm designs its distribution channel, owns assets such as warehouses and logistics infrastructure to deliver the goods to its customers
	Buy	Firm chooses to outsource its distribution function

Make or Buy Decision

A complete (operations) cycle of a product includes 6 stages: plan, design, source its inputs, assemble and manufacture the final product.

A firm may decide to perform all these stages in-house or outsource all these stages or executive some and outsource the rest.

The different *make or buy* options in this regard are summarized in Table 1.

Examples of Firms resorting to different make and buy options are illustrated in Table 2.

ANALYSIS

Jaguar-Land-Rover (JLR), a Tata owned European car maker has resorted to an optimal mix of make and buy policy. It does in-house those activities that serve as its unique-sale-proposition (USP) to the product. It initiates the innovation and carries out research in close collaboration with a team of expert from within and outside organisation. That is, these are a mix of make and buy option. It has its own engine manufacturing and automobile manufacturing

Table 2. Make and Buy Decision of JLR

Tata – JLR or Jaguar Land Rover Car	
Mode of Operation	**Strategy**
Plan & Design	Plans and Designs with help of Warwick University; JLR set up its own National Automotive Innovation Centre (NAIC) in association with Tata Motors Technical Centre WMG and University of Warwick. JLR has an integrated design, research and development centre in Whitley and Gaydon in UK with test track facility.
Source inputs	Inputs sourced from different suppliers include: Plants and Machines such as metal machining systems Basic components such as aluminium sheets, Hardware components such as rubber and plastic sealing, fuel and brake lines, fluid transfer hoses and anti-vibration systems, luxury and quality instrument panels, seats, wheel, electrical systems and other allied items Software (such as navigation and NGI (next generation infotainment) systems developed by third party in collaboration with JLR) Logistics Services: JLR has outsourced its inbound logistics services to firms such as DHL.
Manufacture Engines and Final Product	JLR has its *own engine manufacturing centre* (EMC) at Wolverhampton *Manufacturing of automobiles* in plants at Solihull, Castle Bromwich, and Halewood in UK and plants in Brazil, Austria, China, Slovakia and India JLR has complete knocked down kit *assembly plant* in India, Kenya, Tunisia, Pakistan and Malaysia.
Distribution	Has its warehouses near plants and plans to expand by introducing logistics-operations-centre (LOC) at Solihull, UK. LOC includes approximately 90,000m^2 of warehousing operations space, together with office and parking space. The outbound logistics is outsourced to firms such as Ford in UK, Volvo Logistics in Europe and WWL in China. *JLR manages its own outbound logistics operation in Russia.*

Source: Compiled from:
https://media.jaguarlandrover.com/news/2016/05/jaguar-land-rover-recognises-its-global-supplier-excellence
https://www.drivemidlands.co.uk/wp-content/uploads/2017/05/Jaguar-Land-Rover-its-supply-chain-Mike-Mychajluk-JLR.pdf
https://en.wikipedia.org/wiki/Whitley_plant
https://en.wikipedia.org/wiki/Jaguar_Land_Rover_Gaydon_Centre
http://www.jlr-loc.com/
https://automotivelogistics.media/intelligence/secrets-of-a-success-story

unit. It however manages sourcing of basic inputs and components from companies that have expertise in respective areas, such as Maxion (for Wheels) in Germany, software from Autonavi Software Company Ltd in China and the similar. JLR sets the standards before the suppliers, hold conferences and meeting to keep up to its standards. They have outsourced their inbound and out logistics but manages it in-house for distribution in Russia. Thus, the firm follows a mix of “buy” and “make” decisions for logistics and distribution. Their focus has not been on low cost but on quality of supplies and delivery.

Responsive vs. Cost Efficient Supply Chain

The examples of Wal-Mart and Jaguar-Land-Rover shows that supply chains can be characterised as cost efficient and or responsive supply chain.

Cost Efficient Supply Chain

The firms that pursue cost efficient supply chain achieve their goal through optimization of inventory, assets (such as plant and equipment, warehouses and other facilities), resources (men, money, material and machine) and shipment. Their products are classified as functional products. These products are characterized by certainty in demand, longer life cycle and lower profit margins. They base their decisions on demand forecasting, accordingly follow make-to-stock policy, and said to follow a push strategy. Examples in this category include basic food items, utility items such as heaters, dryers, toiletries, diapers, printers, desktops, writing and printing papers; and similar other items.

Responsive Supply Chain

This category of supply chain primarily focuses on responding to the changing market conditions; and hence, managing the time to deliver, the renewed requirement, is a challenge for the firm. The firm needs to understand and detect the shift in customers' requirement and react to the changing needs through a flexible supply chain. This type of supply chain is meant for innovative products where the firm aims at continually differentiating their products to remain competitive. However, there is uncertainty in demand as the products have shorter life cycle. One way the firm can address this issue is through postponement of final product manufacturing, till it receives the customer order. In such a case the firm is said to follow a pull strategy. The differentiated products can be further classified as *incrementally differentiated products, new products and disruptive products*. Incrementally differentiated products include fashion wears where a new design gets introduced by designer and endorsed by a celebrity; and hence demands change in the product line. In such cases, the demand of inputs up to certain stage in supply chain is certain. For example, a firm in fashion wear market can source inputs such as fabric, stitching items based on the forecast and following the rules of economic-order-quantity while executes final cutting, sewing and dyeing based on actual sale or orders. That is, it awaits its final production of finished goods until it pulls (or knows) the actual customer requirement. Here, firms follow the *dual strategy i.e., push strategy for forecast driven items (to be cost efficient) and pull strategy for customer driven items to be responsive to the changing requirements*. In addition to the volatility of variety, firms also experience sudden surge in demand for the product. For example, during festive seasons, certain fashion wear gets sudden popularity and there is a surge in demand. Alpaca fur toque, the hat wore by the Duchess of Cambridge in Christmas, 2017, became popular and caused immediate spur in demand of similar fashioned hats. Peruvian Connection, a women's fashion wear company quickly recognised the trend and launched it at $99 (https://www.kansascity.com/entertainment/ent-columns-blogs/stargazing/article191674939.html). This was a winter wear and had a life up till the end of cold season.

The firm not only need to adapt the design preferred by the customer but also ramp up the production to meet the sudden surge but short-lived demand. The incrementally-new-products have moderate uncertainty, low shelf life and moderate profit margins. The supply chain managers need to design an *agile and flexible* supply chain (Lee 2002) to address the related challenges. Agility will ensure meeting the changing variety while flexibility will enable the firm to meet changing volume requirements.

Supply Chain Strategy Across Product Life Cycle

The above sections addressed the varied supply chain strategy for different business strategies (such as low-cost, differentiation and focus strategies) and linked them with types of products viz., functional or innovative products. However, the supply chain strategy will also vary with the product life cycle, especially, of differentiated (*incrementally new products, or completely new products*) products. The strategy will further shift for *disruptive or niche products*. Every product passes through the different stages in product life cycle, namely, introduction, growth, maturity and decline.

In the event of *launch of new products*, the products remain untested during its introduction stage. The demand is uncertain and production is done in low volumes. The supply chain manager is not certain about purchase quantity of raw materials and hence need to opt for *flexible-quantity agreements*. In this case the firm may *involve its supplier* in the *planning phase and in co-creation (of product) stage*, to explain the uniqueness in product and uncertainty in demand; and assess *suppliers' capability*. In the *growth stage*, there may be

Table 3. Suppliers' footprint: Decision matrix

Options - Supplier Delivery Elements	In Country	In Region	Global
Response to Deliver	Fast	Intermediate	Fast if Air Else Slow
Cost of Production	High	Medium	Low
Cost of Logistics	Low	Medium	High if Air Low if Sea
Total Cost of Operation (TCO): ∑	∑ (in Country)	∑ (in Region)	∑ (Global)

Source: Author's creation

sudden spurt in demand and suppliers need to possess *flexibility in meeting the increased demand*. This calls for assessment of *suppliers' capacity*. In this stage the firm may even need to opt for transportation by air and ramping up of production to meet the growing demand. Else, there could be lost-sales and decline in company's goodwill.

In many situations a firm need follow dual- strategy, i.e. cost-efficient and responsive strategy, concurrently. A firm needs to have an effective supplier foot print to pursue a dual – strategy. A decision matrix on suppliers' footprint is illustrated in Table 3.

The above table illustrates that the time-to-deliver (TTD) can be minimized by increasing the proximity of suppliers or choosing faster mode of transport. Suppliers located globally are chosen in terms of their capability, capacity and cost of production. Hence the cost of global procurement is cheaper but the time to deliver may be higher. In order to meet the time line faster modes of transport are selected but this result in higher cost. Hence, a trade-off between cost and response time is required to arrive at the decision. The price of the product becomes decisive factor to accommodate higher cost. The supply chain manager needs to base its decision on the expected profit margin of the product. He may expand its supplier footprint from local to global arena and *trade-off between time and cost* according to the market needs. This is suggested for implementing *just-in-time (JIT) mode of operation*. When such a wider supplier base is less available, the supply chain manager needs to adjust the firm's inventory accordingly. In such cases *time-inventory-cost trade-off* becomes the decision making criteria. The firm or their suppliers may have to maintain inventory at different levels to off-set the uncertainty in time to deliver (TTD). This is termed *as vendor-managed-inventory or VMI.*

Hence, a firm need to choose between *JIT delivery and supply-to-stock*. Thus a firm may hold the inventory or the supplier manages the inventory on behalf of the firm i.e., VMI. In VMI system, the firm and its supplier may come to an agreement that the ownership of inventory will be transferred only after it is supplied to the firm. Here, the issue is regarding the motivation of supplier to own, hold and maintain inventory according to a particular firms' need. Or in other words, what happens when the inventory remains un-delivered. The different contract agreements include:

- **Buy-Back Contract:** Here the supplier buys back the unsold or unused items at an agreed price
- **Pay-Back Contract:** Here the firm pay to the suppliers for unsold or unused items stocked by the supplier on behalf of the firm
- **Cost Sharing Contract:** The firm and the supplier agrees for cost sharing of the unsold or unused items irrespective of whoever stocks the item.
- **Flexibility – Quantity:** Here the firm does not assure the supplier of the quantity of purchase in a given period of time. However, in many cases the firm commits a minimum level of consumption of the inventory. The supplier in such a contract does not seek compensation of unsold quantity.

A supply chain manager has very less to do with pricing of the goods; but can articulate the cost of supplies and logistics, as described above. The difference between price and total cost of operation (production plus logistics) defines the profitability of the firm.

In the *matured stage* of the product, the firm may need to introduce incremental differentiation (resulting in *incrementally-new-product*) to keep up its market share and *agility* becomes a key to success. The agility of the suppliers' to adapt to the market needs need to be assessed. The suppliers also have their product - life - cycle. That is, the suppliers who successfully met the target in the introduction and growth stage may fail to sustain in the matured stage if new innovations are introduced. Hence, the supply chain manager needs to decide on *strategy to integrate product-life-cycle and supplies-life-cycle*.

In the *decline-stage (of product life cycle))*, the firm may discontinue with the product. The empanelled suppliers become redundant unless they agree for new supplies for new products.

Assessing Supplier's Ability to Integrate With Product Life Cycle

A supplier, over period of time, may fail to meet the firms' requirement in terms of either time or cost or quality. The performance of the suppliers may be evaluated using relevant key-performance-indicators (KPI), such as time to responds to change request, time to deliver, variations in time, cost and quality. Based on the assessment, a firm a decide to revamp, renew or repeal the contract or relationship.

Example: Apple's Innovation

Apple has been continually introducing new features in the iphone products. Some examples on their innovation include face recognition, prevention from bloat-wares, Siri-Search and iMessages. The suppliers may fail in terms of capability to supply the renewed requirements or capacity to supply the desired quantity or assure the quality of supplies. In addition may not turn out to be cost effective. Apple has introduced - continuous supplier diversity program (https://www.apple.com/procurement/).

The firm may participate in suppliers' decision making process for supplies those are critical in terms of technology and / or availability of suppliers. The firm and supplier may form joint-venture (JV) or special-purpose-vehicle (SPV) or exclusive partnerships to meet exclusive requirements and / or avoid disruptions in supplies. For example Apple and IBM partnered to introduce data analytics in Apple products (https://www.apple.com/in/newsroom/2014/07/15Apple-and-IBM-Forge-Global-Partnership-to-Transform-Enterprise-Mobility/).The partnership is designated as "Mobile First for iOS Initiatives by IBM".

Risk hedging strategy (Lee 2002) is used when there is supplier uncertainty. It calls for empanelment of more than one supplier; pooling and sharing of resources; and increase of safety stock. In the process of supplier selection and empanelment, the firm needs to align its supply chain strategy with corporate environmental strategy for better performance in terms of revenue or cost or both (Wu, et al., 2014).

Floor and Ceiling Pricing Strategy suggests that the firm and the supplier agrees for fixing the lowest price to be payable when price drops and highest price to be paid by the firm when the price escalates. This will enable protection to both the firm when the prices soar and to the suppliers when the prices dip, in highly price-volatile situation.

Summary of Supply Chain Strategy

A supply chain manager has to face four distinct uncertainties, namely demand, supply, price and environmental uncertainties. The environmental uncertainties are the ones where a firm has neither any control nor can influence the environmental factors. These factors are: PESTLE – political, economic, social, technological, legal and environmental (ecological) environment. Any changes in these factors come as a shock and firm need to be resilient to absorb these shocks. This is possible when a firm has a clear mission, vision; and robust strategy and policy (Simchi-Levi et al. 2002). It requires a 360^0 approach where all facets of an organisation, viz., finance, marketing, operations, supply chain management, logistics and similar are integrated and a clear causality established. A supply chain manager needs to align its strategy to the firms' disruption-response-policy. Say, if a firm that imports raw materials, currency depreciation or increase in import duties will to increase in total landed cost (TLC); a question arises that to what extent the firm can sustain the increase in TLC. The most common way to address environmental uncertainties is to introduce redundancy (Simchi-Levi et al. 2002), increase the supplier base, establish global supply chains and manage safety stocks. In case of first two decisions, the structural complexity is likely to increase while increasing safety stocks will lead to lowering of inventory turnover ratio. Hence, an adaptive inventory and supplier policy need to be adopted to continually reassess a firms' inventory (and also the safety stock); suppliers' performance and the total-landed-cost (TLC). Use of artificial intelligence and data mining is gaining significance in an adaptive inventory system.

A multi-criteria decision making model considering different uncertainties may be developed by a firm to carry out policy experimentation and what-if-analysis. This will that aid in study of the behaviour of the supply chain system of the firm under different simultaneous uncertainties of varied extent.

A firm, needs to evaluate its strategic fit between its business and supply chain strategies (Chopra, & Meindl, 2007). It needs to carry out a 4 step approach to achieve the strategic fit. These are: Understanding customer requirements and firms' deliverables; understanding the supply chain capabilities; understanding the uncertainties; and based on these understandings achieving the strategic fit. In case there is a gap between customers' requirement and supply chain performance, the supply chain need to be restructured and strategies re-oriented to meet the super-ordinate goal.

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Chapter 4
Implementing Supply Chain Strategies

ABSTRACT

This chapter emphasizes the key elements required to implement supply chain strategy in a firm. It highlights the differences in supply chain strategies, its alignment with corporate strategies, and the associated drivers of supply chain management. This chapter also highlights the dynamics associated with inventory and success of supply chain of a firm. It tries to provide a framework to resolve the supply chain managers' dilemma as to hold inventory for order fulfilment or to enhance the inventory turnover ratio to maximize profitability. The chapter discusses all facets of inventory management – it includes inventory management of constant as well as dynamic demand. This chapter introduces the concept of adaptive inventory control for non-stationary demand. There are situations when all assumptions of conventional approach may fail and hence points out the importance of application of artificial intelligence and data science in inventory management. This chapter brings out the varied dimensions of contracts that are crucial to have an effective supply chain system. Here the author attempts to put forward an outsourcing decision framework to facilitate make or buy decision. This chapter relates the concept of materials requirement planning (MRP) with independent items. Since supply chains are going global, this chapter introduces the concepts behind global sourcing including the significance of INCO (international commercial) terms.

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INTRODUCTION

Supply chain strategies are based on corporate strategies. A firm decides on the type of product, its marketing mix, market and the way ahead. The firm need to decide on the strategy it would prefer to pursue. The three generic strategies include cost-leadership, differentiation and focus strategies. Thus the products are functional or innovative or personalized product. The corresponding operations strategy are – “make-to-stock” ; “make-to-order”, and “engineer-to-order” respectively. While the supply chain strategies would be a push (for forecast based supply chains) or pull (for order based supply chains in case of engineer-to-order) or push-pull (actual sales based supply chains for innovative products) strategy. The supply chain manager has to trade-off between fill rate and inventory turnover ratio, bulk purchase and obsolescence, EOQ and seasonal availability; and end up measuring its performance on all these parameters including the cash-to-cash cycle (the time elapsed between procurement and realization of sales of final product). He has to continuously adapt its supply chain strategies and decisions based on the performance and changing circumstances. Supply chain function involves 7 stages shown in Figure 1.

Figure 2 illustrates the implementation cycle of supply chain management strategy. It suggests that supply chain strategy is dynamic and continuous re-alignment is necessary to keep up the performance.

INVENTORY

In all three different approaches, namely, make-to-stock, make-to-order and engineer-to-order) the common element is inventory. But inventory decision will vary across the product lines. In case of functional products, a firm, based on forecast, can hold inventory in all stages in supply chain. It

Figure 1. Stages in supply chain management

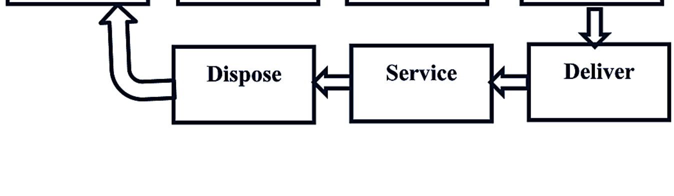
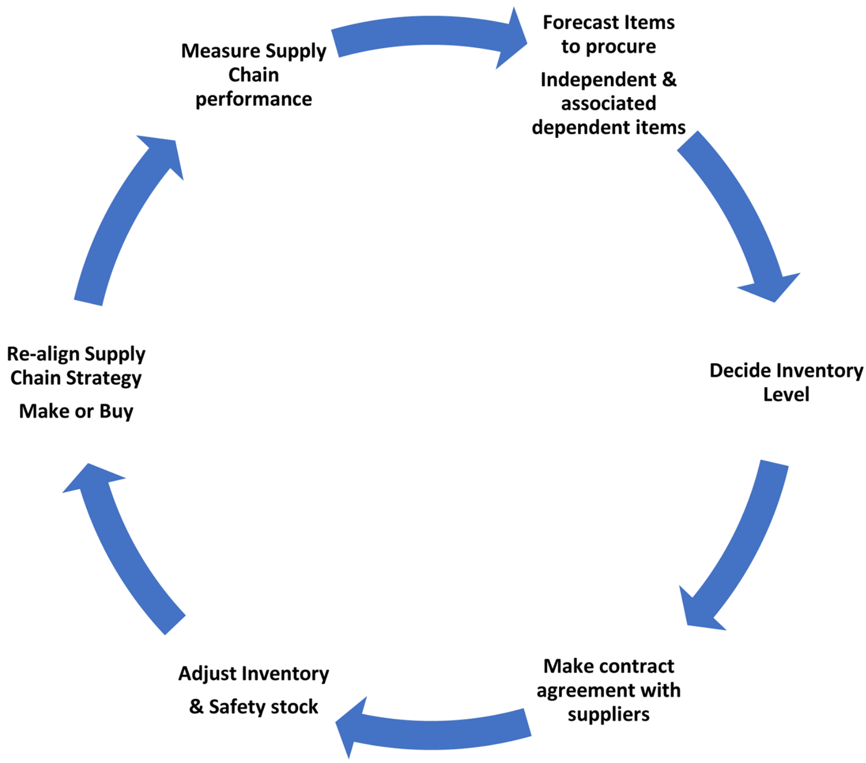


Figure 2. Stages in supply chain implementation



can hold inventory of raw materials and inputs to production and operation in upstream supply chain; can keep inventory of work-in-progress (WIP) in internal-supply-chain and have inventory of finished goods in downstream supply chain. The extent of holding inventory for functional and innovative products would vary across different stages. For innovative products, a firm may not hold inventory of finished goods as its implement pull strategy, where products are manufactured based on actual sales (make-to-order or assemble-to-order). Here firm may hold WIP and postpone manufacture of final product, i.e., produce after receipt of orders. In this type of supply chain different combinations of assemblies or components make different product-types. Such firms keep ready the assemblies and postpone final assembly awaiting final orders.

Example 1: Manufacturing of Wrist Watches

Wrist watches are fancy items and its demand varies rapidly. Most commonly the consumers' preference changes in terms of shape, size and colour of dial, rim and bands of a wrist watch, while the technology remains unchanged. The inventory of watch engine and components constituting dial, rim and bands are maintained, while they are shaped, polished, coloured and integrated on receipt of orders.

Inventory Management

Inventory shields a firm from *uncertainty* in getting raw materials and inputs to production; and finished goods inventory enables to meet the *response time* to the customer. Besides, procurement of raw material in bulk or production of finished good at the level of economies-of-scale *minimizes cost*. In cases where *price* of material is highly *volatile*, firms tend to keep inventory to shield against rising prices. However, there are issues with maintaining inventory. These are:

1. Cost of maintaining inventory
2. Obsolescence of inventory

Thus inventory has different perspectives; and trade-off between these perspectives govern the decision making. These are:

- **Inventory Holding Cost vs. Lost Sales:** This implies that lower inventory would result in lower holding cost but at the same time may result in lost sales
- **Lost Sales vs. Customer Satisfaction:** This in other words means that a firm has to decide between service levels and *fill rate* of finished goods inventory. Fill rate refer to percentage of total demand met while service levels imply number of customers satisfied or number of customers that do not experience a stock out .

Example: let's consider a retailer selling 5 Litre pack of car engine oil. Let's assume that on an average, out of 20 requests for the engine oil per day, 19 requests come from individual clients who require only a pack of engine oil. 1 (request out of 20) comes from a car mechanic. The mechanic orders for 20 packs required for his repair works

If the retailer keeps 20 packs in stock, and if we assume his lead time of supply to be of 1 day, then at any given day the service level is 95% (19/20=0.95). As orders of 19 out of 20 clients are met. However, the mechanic's order is declined as the stock never gets big enough to cover the order of 20 packs a day. The total demand per day stands at 39 (19+20) packs. Whereas 19 out 39 packs can only be supplied. Thus, the fill rate is close to 50% ($19/(19+20) \approx 0.5$).

Fill rate gives credit for the extent of fulfilment of order. Service level measures the performance in terms of customer being satisfied or not satisfied. When the numbers of customers are less fill rate appear to be more applicable as in business-to-business (B2B) setting.

In retail environment it is difficult to find out the number of customers who are not satisfied and hence service level is calculated from fill rates, as this helps to determine the z-score needed to determine the safety stock, explained in latter part of this chapter.

The concept of service level has different perspectives. These are:

1. Service Level as percentage of total demand met (same as *fill-rate*)
2. Service Level as percentage of total customers served
3. Service Level as percentage of time spent without being out-of-stock over a total period

Example: A retail store remains open from 10 a.m. to 5 p.m. It has a lead time of supply of 1 day. At opening, the store has 11 units of product X in stock. During the day, 2 customers enter the store. The first customer comes at comes at 10 a.m., willing to buy 11 units, and the second at 5 p.m., willing to buy 1 unit of product X. The store sells 11 items to the first customer, and hence there after the store remains out-of-stock.

If the service level represents the percentage of the total demand in units that is met, then the service level for the day is 91.7% (11 units sold out of a total demand of 12). This is same as *fill rate. Here* "*[100-91.7= 8.3%] corresponds to lost sales"*

If the service level represents the percentage of customers served, then the service level refers to *"client satisfaction"*. In this case it is 50% (1 customer with 11 units request has been fully satisfied, and 1 returned un-served).

If the order was for 1 unit by each of the 2 clients then the definition 1 and 2 are similar. The fill rate is similar to service level. *That is for equal orders by all customers fill rate is similar to service level.*

If the service level represents the percentage of the time spent without being out-of-stock over a total period, then the service level for the day is 10% (the store is out-of-stock after 1 hour, over a 10-hour day). Note that, if sales were perfectly flat in time, then this definition would also become equivalent to fill rate.

It goes to show that, when trying to measure service levels, it is first important to define what it is exactly one is measuring.

Hence, the decisions need to be taken, as how much inventory (inventory-level) is required to be maintained and how long a material remains in inventory.

- **Ordering Cost vs. Holding Cost:** The common way to determine the EOQ is to trade-off between the ordering cost and holding cost.
- **Bulk Purchase vs. Inventory Obsolescence:** Bulk purchase reduces per unit cost. However, bulk purchase of perishable items is not advisable if the usage rate is not commensurate with its shelf life. For example, shelf life of paints stored after opening of sealed containers is lower than its shelf life when stored in sealed containers.
- **Continuous vs. Seasonal Availability:** Certain items may be available during certain part of the year; in such cases procurement quantity may not be as per traditional EOQ decisions as purchases have to be completed during the season. For example, in some cases mining of materials are done during dry seasons and remain suspended in wet seasons. Hence procurement during dry seasons is preferred. This has dual benefits: One that it ensures availability and second, that dry ores or its refined ones are free from moisture that would otherwise cause increase in weight and reduction in quality.

Inventory Level

Inventory ties up working capital, besides has a cost of storing. The sum of all these cost is termed as holding or carrying cost of inventory. The company need to decide between holding cost of inventory and the *inventory turnover ratio.* This is a ratio of cost of goods utilized in production and cost of average inventory held during the period. Say, cost of goods used is 100$ while cost of average inventory is 25$, the inventory turnover ratio stands at 4. High ratio indicates that the firm is not holding excessive stock in hand and blocking its working capital. For finished goods, it is the ratio of cost of goods sold and cost of average inventory held during the period. Average inventory is calculated by dividing the sum of starting and ending inventory by 2. This is an approximate average inventory level. On may use current inventory level in lieu of this average. However, the approximate average is more accurate than current inventory level if there has been significant difference or variation in the size of the inventory in the given period.

Firms aiming at reducing inventory level may experience stock-outs and backlogs. In order to maintain a high inventory turnover ratio by lowering the average inventory a firm need to have efficient responsive supply chain.

Continuous Review Model or Fixed Quantity (Q) Model

In this approach the inventory level is continuously monitored and wherever the inventory falls below the re-order level, a fixed quantity equivalent to economic-order-quantity (EOQ) is placed. Re-order level can be computed with deterministic and stochastic demand pattern.

Reorder Level (ROL) Under Deterministic Assumptions

Here the lead time and demand are known (i.e., constant). ROL is computed as:

Reorder Level (R) = Lead time in days (L) x Daily Average Usage or demand (d)

i.e., $R = dL$ (1)

Reorder Level (ROL) Under Stochastic Assumptions

Here the lead time and demand are random. ROL is computed as:

Reorder Level = Lead time in days x Daily Average Usage + Safety Stock (SS)

i.e., $R = dL + SS$ (2)

Equation 2 shows that reorder level depends on *lead time* to supply (for raw materials) or lead to production (for finished goods) as the case may be; daily average usage; and *safety stock.*

Safety stock is computed in terms of number days a firm would like to keep buffer and material usage per day. Safety stock is the amount by which the reorder point exceeds the expected (average) lead time demand.

Safety stock can be computed as:

$$Safety\,Stock\left(SS\right)=\frac{Number\,of\,days\,for\,which}{buffer\,is\,proposed\,to\,be\,kept}\left(D_b\right)\times Daily\,Average\,Usage\,per\,day\left(d\right)$$

i.e., $SS = D_b * d$ (3)

However, when the lead time or demand during lead time or both are random and their distribution is assumed to be normal; the safety stock can be computed as:

Variable Lead Time and Constant Demand (During Lead Time)

$$SS = Z * d * \sigma_L \tag{4}$$

and

$$R = d\overline{L} + Zd\sigma_L \tag{5}$$

where:

d = constant daily demand
$\overline{L}$ = average lead time
σ_L = standard deviation of lead time
$d\sigma_L$ = standard deviation od demand during lead time
$Zd\sigma_L$ = safety stock

Variable Demand (During Lead Time) and Constant Lead Time

$$R = \bar{d}L + Z\sigma_d\sqrt{L} \tag{6}$$

where:

R = reorder point
$\bar{d}$ = average daily demand

L = lead time
σ_d = the standard deviation of daily demand
Z = number of standard deviations corresponding to service level probability
$Z\sigma_d\sqrt{L}$ = safety stock

Variable Demand (During Lead Time) and Variable Lead Time

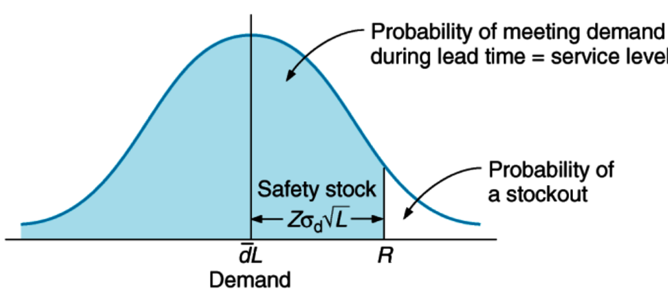
$$R = \bar{d}\bar{L} + Z\sqrt{(\sigma_d)^2\bar{L} + (\sigma_L)^2\bar{d}^2} \quad (7)$$

where:

$\bar{d}$ = average daily demand
$\bar{L}$ = average lead time
$\sqrt{(\sigma_d)^2\bar{L} + (\sigma_L)^2\bar{d}^2}$ = standard deviation of demand during lead time
$Z\sqrt{(\sigma_d)^2\bar{L} + (\sigma_L)^2\bar{d}^2}$ = safety stock
Z = Number of Standard deviations required for specified service level; for example when Z = 1.65 the required service level is 95%;

Chopra et al., (2004) distinguishes between fill rate and cycle service level. They suggest that the fill rate measures the proportion of demand that is met from stock, whereas the cycle service level measures the proportion of replenishment cycles where a stock out does not occur. They concluded that:

Figure 3. Safety stock with variable demand



1. "For cycle service levels above 50% but below a threshold, reducing lead time variability increases the reorder point and safety stock.
2. For cycle service levels above 50% but below a threshold, *reducing* the *lead time variability increases* the reorder point and safety stock, whereas reducing the ***lead time*** *decreases* the reorder point and safety stock."

Economic Order Quantity

Whenever, inventory falls below reorder level, an order is placed. The quantity of order placed is determined by trading off between holding costs and ordering cost of material. This is termed as economic-order-quantity or EOQ. Hence EOQ can be derived as:

[Total Ordering Cost] = [Total holding Cost]

where;

[Total Ordering Cost] = [Number of Orders Placed] x [Ordering Cost (C_O)]

[Total holding Cost] = [Cost of holding inventory (C_h)] x [Average Inventory (Q/2) per annum]

where;

[Number of Orders Placed] = (Annual Demand (D) ÷ Quantity Ordered per Order (Q))

That is,

$$(D \div Q) \times C_O = C_h \times (Q \div 2) \tag{8}$$

or

$$Q^2 = \{[2 \times D \times C_O] \div C_h\}$$

or

$$Q = \sqrt{\{[2 \text{ x } D \text{ x } C_O] \div C_h\}} \quad (9)$$

The quantity Q for which total ordering cost is equal to the total holding cost of inventory per annum is the economic-order-quantity (EOQ). Hence equation 9 can be written as:

$$EOQ = \sqrt{\{[2 \text{ x } D \text{ x } C_O] \div C_h\}} \quad (10)$$

In the above computation it is assumed that supplies are instantaneous and there are no stock outs.

The *fixed-order-quantity model* is useful for *high valued and essential items*. Thus items can be classified in terms of annual cost and usage. This classification is termed as *ABC classification*. Here items under class “A” are fewer in numbers but have high annual cost and usage, say above 70% in cost and usage. The annual cost-usage is computed by multiplying annual demand with per unit cost. The items that cumulate to 70% of the total annual volume cost are called class “A” items. These items constitute 10 to 15% of total volume of inventory in terms of units. Class “B” items have annual volume cost of around 25% and constitute 30% of inventory items. The rest of items, that is around 55% of inventory items but have annual volume cost of around 5% are termed as class C items. Some items are “vital (V)” to the product, and some are essential (E) while some are desirable (D) to the overall product. This way of classifying items is termed as *“VED” classification*. Items that have high annual volume cost and are vital in nature need more attention. Higher safety stock, being vital items, will ensure there availability but at the same time it will lead to increase in holding cost as they have high unit cost. Hence, a supply chain manager need to reduce safety stock at the same time ensure uninterrupted supply. This is possible with *right kind of relationship with right supplier through appropriate contracts.* In industry it is observed that, for such items, firms enter into joint venture or long term contracts with suppliers. For example, Boeing has exclusive partnership agreement with Roll-Royce for supply of aircraft engines.

EOQ for Discounts on Bulk Purchase

In certain cases firms may be offered price discount for order quantity more than a certain level. Say, price of an item is 10$ when quantity is above 100 units, while it is 12$ below this quantity. A firm may be tempted to buy 100 or more units to avail the price discount. There are two issues with this decision. One, with price discount purchase cost may come down but holding or carrying cost may go up. Holding cost is computed as percentage of unit price of material. Say, 10% of unit price i.e. 10% of 12$ or 10$ as per the order quantity. Hence, one needs to determine the total inventory cost that is sum of carrying or holding cost, ordering cost and purchase cost. The quantity for which the total inventory cost is minimized will be the desired economic order quantity when price discounts are availed.

Example 2

The offer from the supplier is shown in Table 1.

We need to calculate EOQ i.e Q* when annual demand is 1000 units with inventory holding cost (C_h) equal to 10% of unit price and ordering cost (C_o) equal to 50$.

As a first step, we calculate EOQ i.e Q* for the various price range:

$$Q^*(\text{for price} = 5\$) = \sqrt{[(2D\,C_o) \div C_h]} = 447$$

$$Q^*(\text{for price} = 4.75\$) = \sqrt{[(2D\,C_o) \div C_h]} = 459$$

$$Q^*(\text{for price} = 4.65\$) = \sqrt{[(2D\,C_o) \div C_h]} = 464$$

But to avail 7% discount the minimum order quantity has to be 500. Hence comparing the total inventory cost shown in Table 2.

Hence Q* = 459 gives the lowest total inventory cost.

Dynamic Demand Inventory Models

EOQ is optimal for constant demand and static cost parameters. When the variability of demand is such that the coefficient of variation (standard deviation ÷ mean) is greater than 20%, the demand is said to be dynamic

Table 1.

Offer	Quantity	Discount	Price
1.	0 to 99	O%	5$
2.	100 to 499	5%	4.75$
3.	500 and above	7%	4.65$

Table 2.

Offer	Price	Order Quantity	Carrying Cost	Ordering Cost	Item Purchase Cost	Total Cost
1.	5$	447	447 x (0.1 x 5) = 223.50	(1000 ÷ 447) x 50 = 111.86	447 x 5 = 2235	2570.36
2.	4.75$	459	459 x (0.1 x 4.75) = 218.03	(1000 ÷ 459) x 50 = 108.93	459 x 4.75 = 2180.25	2507.21
3.	4.65$	500	500 x (0.1 x 4.65) = 232.5	(1000 ÷ 500) x 50 = 100	500 x 4.65 = 2325	2657.5

Number of orders = Annual demand / Q*

and EOQ model will not be applicable. In such case well known heuristics inventory models such as Silver Meal method (because of simplicity and computational efforts for capacity constrained problems) or Least – Unit – Cost (LUC) or Part – Period – Balancing (PPB) methods are used. Silver Meal method is said to perform better than LUC. Wagner-Whitin method is optimal for discreet demand pattern but requires more computational effort compared other single-level-lot-sizing-without-resource- constraint (SLUR) techniques. A comparison of methods has been attempted by several authors (Karimi et al., 2003; Bahl, et al., (1987); Baciarello et al, 2013). This problem of dynamic demand is a NP-hard problem and hence computational effort is of prime importance for consideration apart from the factors such as ease of understanding and implementation.

Silver Meal Method

This method is applied when coefficient of variance is high. This means that demand varies every month and hence is dynamic. In this method the total cost comprising holding cost and ordering cost are computed to calculate average cost per period. The objective is to minimize average cost per period. The major assumptions are that the quantity needed in a period is used at the beginning of the period, while the holding cost occur at the end of the period. In this method the average cost per period is computed in lieu of average cost per unit.

Here, the order launched in period i will group the requirements of all the periods from i to j until the following condition is reached:

$$\frac{S + h\sum_{k=i}^{j+1}(k-i)d_k}{j+1} > \frac{S + h\sum_{k=i}^{j}(k-i)d_k}{j}$$

that is, given i, we need to find the greater value of j subject to the condition:

$$F = \sum_{k=i}^{j}(i-k)d_k + j(j-i+1)d_{j+1} \leq \frac{S}{h}$$

where, S is the ordering cost and h is the holding cost.

For example, Table 3 shows the dynamic demand over the months for a particular product, with coefficient of variation (25%) greater than 20%.

The average cost is computed as shown in Table 4.

The above computation of need to be extended so long the average cost (C_A) continues to decrease. The order quantity is equivalent to the sum of demand per month for the period prior to the month or the point from where C_A starts increasing. The shape of C_A graph plotted over months would assume a U shape (Figure 4)

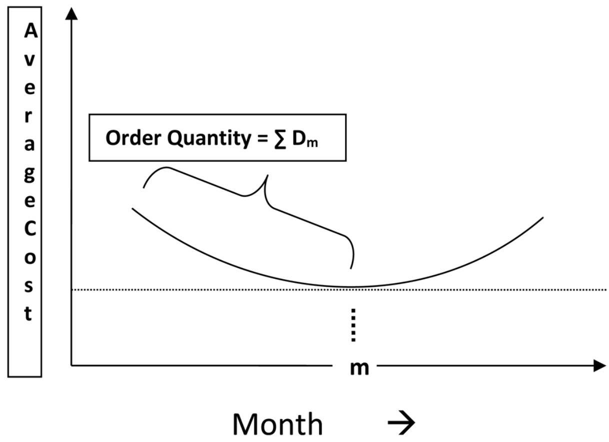
Table 3. Dynamic demand over the months

Month	1	2	3	4	5	6	7	8	9
Demand	D_1	D_2	D_3	D_4	D_5	D6	D_7	D_8	D_9
Demand	20	30	23	19	32	28	20	16	32

Table 4. Average inventory cost computation

Order Period	**Ordering Cost**	**Holding Cost**	**Average Cost per Period (C_A)**
1	C_O	0	$(C_O) \div 1$
2	C_O	C_hD_2	$(C_O + C_h * D_2) \div 2$
3	C_O	$C_hD_2 + 2C_hD_3$	$(C_O + C_h * D_2 + 2 * C_h * D_3) \div 3$
4	C_O	$C_hD_2 + 2C_hD_3 + 3C_hD_4$	$(C_O + C_hD_2 + 2C_hD_3 + 3C_hD_4) \div 4$
5	C_O	$C_hD_2 + 2C_hD_3 + 3C_hD_4 + 4C_hD_5$	$(C_O + C_hD_2 + 2C_hD_3 + 3C_hD_4 + 4C_hD_5) \div 5$
6	C_O	$C_hD_2 + 2C_hD_3 + 3C_hD_4 + 4C_hD_5 + 5C_hD_6$	$(C_O + C_hD_2 + 2C_hD_3 + 3C_hD_4 + 4C_hD_5 + 5C_hD_6) \div 6$

Figure 4. Illustration of silver-meal heuristics



Example 3: Silver Meal Method

Order Quantity = $\sum D_m = D_1 + D_2 + D_3 = 20 + 30 + 23 = 73$

The next order would be calculated by considering the demand for remaining periods, i.e., month 4 onwards (Tables 7 and 8).

Table 5.

Month	1	2	3	4	5	6	7	8	9
Demand	D_1	D_2	D_3	D_4	D_5	D6	D_7	D_8	D_9
Demand	20	30	23	19	32	28	20	16	32

C_O = 80$; C_h=1.20$

Table 6.

Month	1	2	3	4	5	6	7	8	9
Demand	D_1	D_2	D_3	D_4	D_5	D6	D_7	D_8	D_9
Demand	20	30	23	19	32	28	20	16	32
C_O	80$	80	80	80	80	80	80	80	80
C_h	0	C_h*30	Ch * (D_2 + 2D_3)	Ch * (D_2 + 2D_3+ 3 D_4)	Ch * (D_2+2D_3+3 D_4 + 4D_5)	Ch * (D_2+2D_3+3 D_4 + 4D_5+ 5D_6)			
C_A	80/1	(80+36)/2	91.2/3	159.6/4	313.2 /5				
C_A	80	58	57.0667	59.9	78.64				

Table 7.

Month	1	2	3	4	5	6	7	8	9
Demand	D_1	D_2	D_3	D_4	D_5	D6	D_7	D_8	D_9
Demand	20	30	23	19	32	28	20	16	32

Table 8.

Month	1	2	3	4	5	6
Demand	D_4	D_5	D6	D_7	D_8	D_9
Demand	19	32	28	20	16	32
C_O	80	80	80	80	80	80
C_h	0	C_h*30	Ch * (D_2 + $2D_3$)	Ch * (D_2 + $2D_3$ + $3D_4$)	Ch * (D_2+$2D_3$+ $3D_4$ + $4D_5$)	Ch * (D_2+$2D_3$+$3D_4$ + $4D_5$+ $5D_6$)
C_A	(80+0)/1	(80+38.4)/2	(80+33.6)/3	(80+24)/4	(80+19.2)/5	(80+38.4)/6
C_A	80	59.2	56.8	52	49.6	59.2

Order Quantity = $\sum D_m = D_1 + D_2 + D_3 + D_4 + D_5 = 19 + 32 + 28 + 20 + 16 = 115$

Least Unit Cost Method

In this method instead of computing average cost per period, the average cost per unit demanded is calculated as shown in Table 9.

Example 4: Least Unit Cost Method

$C_O = 80\$$; $C_h = 1.20\$$

Order Quantity = $\sum D_m = D_1 + D_2 + D_3 = 20 + 30 + 23 = 73$

Similarly the next order would be calculated by considering the demand for remaining periods, i.e., month 4 onwards (Tables 12 and 13).

Table 9.

Order Period	Ordering Cost	Holding Cost	Average Cost per Unit (C_{AU})
1	C_O	0	$(C_O) \div D_1$
2	C_O	C_hD_2	$(C_O + C_h * D_2) \div (D_1 + D_2)$
3	C_O	$C_hD_2 + 2C_hD_3$	$(C_O+C_h*D_2 + 2*C_h*D_3) \div (D_1 + D_2+D_3)$
4	C_O	$C_hD_2 + 2C_hD_3+ 3C_hD_4$	$(C_O + C_hD_2 + 2C_hD_3+ 3C_hD_4) \div (D_1 + D_2+D_3+D_4)$
5	C_O	$C_hD_2 + 2C_hD_3+ 3C_hD_4+4C_hD_5$	$(C_O +C_hD_2 + 2C_hD_3+ 3C_hD_4+4C_hD_5) \div (D_1 + D_2+D_3+D_4+D_5)$
6	C_O	$C_hD_2 + 2C_hD_3+ 3C_hD_4+4C_hD_5+5C_hD_6$	$(C_O +C_hD_2 + 2C_hD_3 + 3C_hD_4 + 4C_hD_5 + 5C_hD_6) \div (D_1 + D_2+D_3+D_4+D_5+D_6)$

Table 10.

Month	**1**	**2**	**3**	4	5	6	7	8	9
Demand	$\mathbf{D_1}$	$\mathbf{D_2}$	$\mathbf{D_3}$	D_4	D_5	D6	D_7	D_8	D_9
Demand	**20**	**30**	**23**	19	32	28	20	16	32

Table 11.

Month	1	2	3	4	5	6	7	8	9
Demand	D_1	D_2	D_3	D_4	D_5	D6	D_7	D_8	D_9
Demand	20	30	23	19	32	28	20	16	32
$\mathbf{C_O}$	80	80	80	80	80	80	80	80	80
$\mathbf{C_h}$	0	36	91.2	159.6	313.2				
$\mathbf{C_{AU}}$	4	2.32	2.34520548	2.60434783	3.17096774				

$$\text{Next Order Quantity} = \sum D_m = D_1 + D_2 + D_3 = 19 + 32 + 28 = 79$$

Fixed-Time Period Model (P Model)

The other way of managing inventory could be following a *fixed-time period model.* In this approach, the inventory levels are monitored at periodic timae interval, say every month. At time of assessment, if the level of inventory falls below the desired level, order for the quantity equal to the difference (Q – I) between the desired quantity (Q) and actual quantity (I) is placed. There

Table 12.

Month	1	2	3	4	5	6	7	8	9
Demand	D_1	D_2	D_3	D_4	D_5	D6	D_7	D_8	D_9
Demand	20	30	23	19	32	28	20	16	32

Table 13.

Month	1	2	3	4	5	6
Demand	D_4	D_5	D6	D_7	D_8	D_9
Demand	19	32	28	20	16	32
C_O	80	80	80	80	80	80
C_h	22.8	99.6	200.4	296.4	392.4	622.8
C_{AU}	5.41052632	3.52156863	3.54936709	3.8020202	4.10782609	4.78095238

are possibilities of stock outs in-between the review periods. Hence larger safety stock is proposed in such cases. This approach is mostly applicable for low cost items falling under desirable category (under VED analysis). This system does not require continuous monitoring. The target or desired quantity to be maintained is given by expression 11.

$$Q = (T+L) * d + z * (\sigma_{T+L}) * \sqrt{(T+L)} \tag{11}$$

where,

Q = quantity
T = Review Time
L = Lead Time
d = Average daily Usage
z = Number of Standard deviations required for specified service level; i.e., when z = 1.65 the required service level is 95%
σ_{T+L} = Standard deviation of daily usage during review and lead time.

Single Period Inventory

Inventory management becomes a challenge for goods whose post sales inventory cannot be maintained. For example, newspaper selling requires a newspaper vendor to decide on the quantity of newspaper he would stock for day. This is critical in the sense that if his stocks do not sale that day, the items are rendered useless or obsolete. On the other if he buys less than the demand, he losses the opportunity to earn revenue. Hence, decisions are required to be based on probability of being in stock (i.e probability that there are **no** stock outs). This is calculated as given in expression 12.

$$P \leq C_u \div (C_o + C_u) \quad (12)$$

where

P is probability being in stock.
C_u is cost of under stocking
C_o is cost of over stocking

The newspaper vendor would increase the inventory so long as the probability is less than equal to $[C_u \div (C_o + C_u)]$. The buyer may compute the cost of under stocking or over stocking based on the price he buys and sells the item respectively.

Example 3: Stocking Decision for Newspaper Vendor

Let cost of a newspaper be 1$
Let selling price of newspaper be 3$

$C_{u\,(}$cost of under stocking) = 3 – 1 = 2$

C_o (cost of over stocking) = 1$

P = 2 ÷ (1 + 2) = 0.66, the probability of being in stock.

If the average demand for newspaper is 100 units with standard deviation equal to 10, then the optimal quantity is given by the formula:

Q = Mean + z times the Standard Deviation

The z value equivalent to 0.66 (from the z table) is 0.41

Q = 100 + 0.41 x 10 = 104 units

Such instances are also observed in service industry such as passenger-airline industry. An airline may decide to overbook the seats for a particular trip on the premise that that there will be last minute cancellations. However, if the cancellations are less than overbooking numbers, the airline has to pay compensation that is the C_o or cost of overbooking.

Example 4: Overbooking Decision for an Airline

Let airline seat booking rate be 2$

Let compensation to be paid if seats purchased are not confirmed be 4$

$C_{u\,(}$cost of under stocking) = 2$

C_o (cost of over stocking) = 4$

P = 2 ÷ (4 + 2) = 0.33, the probability of being in stock.

If the average demand for seats is 100 units with standard deviation equal to 10, then the optimal quantity to be *overbooked* is given by the formula:

Q = Mean + z times the Standard Deviation

The z value equivalent to 0.33 (from the z table) is -0.44

Q = 100 - 0.44 x 10 = 96 units

Such cases where items have one-time demand, i.e., for a single period and the inventory are determined based cost of under-stocking and overstocking is referred as *single-period-inventory model.*

Adaptive Inventory Control

The continuous and periodic inventory models yield good results for items that exhibit less volatility. The heuristic models are applied when the demand fluctuates (items whose coefficient of variation is greater than 20%). Another means to control volatile demand is through adaptive inventory control approach. Here inventory decisions are taken by dynamically adjusting the control parameters of inventory such that it satisfies the desired service level (Kim,et al., 2005). . The target service level refers to the percentage of customer demands that have to be satisfied during the *lead time* (time interval between order placement time and inventory replenishment time).

The firm adjusts the inventory while it monitors the service level during the lead time: (supplier's lead time + transportation lead time + safety lead time). This inventory is adjusted to the extent of the difference between the target service level and the actual service level. This can be expressed as -

Adjusted Inventory: Target Service Level – Actual Service Level

The safety stocks are adjusted. Safety stocks with low service-level deviations are given high selection probabilities. This is a learning algorithm where the model continuously learns from its past decisions and continually makes corrections. The safety stock is evaluated as:

NewValueEstimate = OldValueEstimate + Step_Size [Current_Value − Old_Value_Estimate]

This is an Exponential Smoothing method, where step size is a constant (value lying between 0 and 1) that denotes the weight accorded to the absolute difference between the current safety stock minus the estimated safety stock. StepSize is a learning parameter that decides learning speed. It is normally set to a constant, such as 0.1, which has been experimentally verified to be desirable, especially in non-stationary environments (Sutton and Barto, 1998). Here the assumptions are:

- Demand is non-stationary that is, the mean and variance of the demand distribution changes with time.
- Supplier's orders are always satisfied after a constant lead time from a perfectly reliable single outside source.
- For each supply, transportation lead time from the supplier to the firm is given as a constant.
- However, the firms' actual lead times are not constant unless the supplier has enough inventories to meet the firms' orders.
- Finally, if customer demands are not satisfied at sales points of time, the demands are treated as lost sales

This algorithm turns out to be ineffective when the assumptions do not hold good. In todays' world, with the advent of artificial intelligence incorporating data mining techniques and natural language processing, the adaptive inventory control appears to be the future approach, especially for non-stationary customer demand. The choice of data mining techniques affects the decisions. Modern methods such as non-parametric ensemble techniques namely random forest are expected to give better association rules for improved decision making. This area can be considered for future research especially to draw a comparison with the conventional approaches.

Sourcing and Contracts

A firm may decide to source the raw materials or components or assembled components; or the finished products. The extent of outsourcing will primarily depend on 5 factors, namely, business goals, internal competency, internal capabilities, external competency and capabilities and risk. The decision matrix for outsourcing of an input or set of inputs or assembly of inputs or product as a whole can be laid down as shown in table 4.1. The internal competency refers to the firms' ability to design, manufacture and manage its operations, while internal capacity refers to availability of infrastructure, i.e., plant, machinery, equipment and other similar resources. A firm may have competency to manufacture but may lack capacity to produce. In such cases firm may carry out the planning and design, while letting out the manufacturing to external agency that has the capacity.

The decision on outsourcing are based on the flowing premises:

1. Identifying the core and non-core activities by the firm. The firm needs to identify its key result areas (KRAs). The activities that directly influence the KRAs can be termed as the core activities where the firm need to focus and adopt any strategy that meets the firms' requirements.
2. Based on the core activities, the firm needs to identify the unique-selling-propositions (USPs) that gives it a cutting edge over competitors
3. The firm need to weigh the risk of outsourcing the core activities in terms of losing the trade secret or quality of product and delivery. That is, the firm need to identify core of core.
4. The core activities where risk is high, the firm may perform the same in-house subject to its ability to invest (build capacity) and acquire competency to design, operate and manage operations. The risk arises out of possibility of design and process getting copied or diluted, causing the firm to lose its uniqueness.
5. Firm may not find an external agency for outsourcing as the job may require a specialist which external firms may not find it attractive over

Table 14. Outsourcing decision matrix

Availability	External Competency	External Capacity	No External Competency and Capacity
Internal Competency	A. *Firm may design in-house & Outsource manufacturing* if: i. Internal capacity is less or does not exists ii. External capacity exists. B. *May* Outsource *design and manufacturing* if: i. Business Goals permit ii. External capacity exists	A. *Firms may design in-house* B. *May Outsource manufacturing if:* i. Internal capacity is less than required or does not exists ii. Business Goals permit C. *May outsource design and manufacturing if*: i. Business Goals permit ii. Firm has less or no capacity	Firm design and manufactures In-house
Internal Capacity	*May outsource design* (i.e., take external support); Firm has internal capacity and hence outsource operations and management of its infrastructure and not opt for complete outsourcing; OR Self-fabricate or manufacture in-house till capacity permits.	Firm has internal capacity and hence outsource operations and management of its infrastructure and not opt for complete outsourcing, *May outsource manufacturing* if: Capacity of the firm does not meet the requirement. That is, outsource to the extent company falls short to meet the demand in-house. Business Goals permit to outsource, irrespective of having internal capacity	In-house
Internal Competency and Capacity	*May outsource if:* Business Goals permit	*May outsource if:* Business Goals permit	In-house
No Internal Competency and Capacity	Outsource	Outsource	Avoid such operations

other offers received by them. The firms in such cases may need to build there competency.

6. In certain cases risk may arise out of non-availability of external sources or due to price volatility; and as such a firm may decide to own its operations. The recent examples of scarcity in availability of lithium and cobalt for batteries have led the electric car manufacturer to either own mines or form joint-ventures (JV) for extraction and mining or enter into long term contract with mine owners.
7. Activities where risk of outsourcing is high, and the firm has acquired competency, but has no or limited capacity may plan and design in-house and outsource manufacturing under contract manufacturing with exclusive non-disclosure agreement and protection of intellectual property rights (IPR).

Example 5: IBM's Operating System Taken Over by Microsoft

IBM allowed Bill Gates's QDOS to operate their code for personal computer, named Acorn. Microsoft was allowed to retain the ownership and the firm licensed the software to hardware manufacturers who were competitors of IBM. Over the period everyone knew about Microsoft's DOS; and IBM lost its edge over the operating system for PC.

1. Core activities where risk of outsourcing is low, firm may acquire competency to define and design these activities but outsources manufacturing.
2. Activities that fall under non-core category, where firms find it economical to outsource, may get these done through external agency. This is subject to availability of external firms' competency and capability. Else the firm will have no option but to carry out these non-core or low risk core activities in-house. Sometimes, a company may consider managing its own certain activities that, apparently, are non-core to the firm to leverage from in-house operations.

Example 6: Amazon's Warehouses

Amazon started its business in 1994 as cyberspace company, i.e., as an Internet retailer, now owns warehouses and logistics companies. In other words, Amazon, what it thought once to be done by others, namely, storing and supplying and has now taken over these activities as its own operation instead of outsourcing it completely.

In-house operations enable a firm to control and influence the activities; and hence their performance. A firm can only influence, but cannot control, outsourced agencies with well defined contracts. Hence, a company needs to assess its comparative advantage of doing in-house over outsourcing. Increase in suppliers due to outsourcing make management of suppliers difficult and increases the supply chain complexity. A firm may consider tightly knitted partnership with suppliers in line with *keiretsu* model. This approach suggests creation of community of business partners and integrating them with through a forum such as EMIT- consortium created by Boeing or through Keiretsu Forum that brings together equity angel investors, venture capitalist and corporate and institutional investors, founded by Randy Williams in 2000. Randy Williams is a global investment company.

Example 7: The Environmental Materials Information Technology (EMIT) of Boeing

Boeing initiated this collaborative project for its product design so as to ensure compliances of environmental objectives and regulations, which varies from country to country. The business partners use information technology solutions that are centred on information and decisions relating to materials and processes. The key focus area include compliance of REACH regulation laid down by European Union to avoid risk relating to restricted substance and critical materials; and design the product such that it reduces energy usage or carbon foot print.

CONTRACTS

Contracts are the ways a firm sets up its relationship with its business partners. The contract with suppliers ranges from spot purchases to joint ventures or creation of special purpose vehicles.

1. **Spot Purchases:** For items that are required intermittently, having low cost, low capital outflow, with large number of suppliers available in the market, a firm may not choose to enter into any binding with the suppliers. The procurements are made as and when required.
2. **Tendering:** Procurement through tendering is done when:
    a. Procurement value of items is moderate or high, competitive bidding through the process of tendering ensures a low cost.
    b. There is no scarcity in availability of suppliers.
    c. The firms is aware of the specifications and dictates the terms and conditions. This approach is treated as "white box" contracts. *or the*
    d. Firm spells out the end requirement while the supplier offers the best input or solution that meets firms' requirement. This approach is treated as "black box" contracts.

Collaborative Contracts

This approach is resorted when:

- Items are vital or essential or are scarce or exhibit price volatility:

A firm approaches a firm for supply of inputs and materials, either directly to individual firms or through open bidding seeking request for proposal (RFP) and offers or quotes (RFQ) under following conditions:

1. **Cost Sharing Contracts:** Firm agrees to share cost of production with supplier to ensure timely supplies at right price.
2. **Revenue Sharing Contracts:** Firm agrees to share revenue it generates from sales of its goods and services with supplier.
3. **Buy Back Contracts:** Firm agrees to procure a minimum quantity of supplies with a provision that in case of un-used goods, the same would be taken back by the supplier at a reduced price. The assumption here is that the supplier would sell it to the other firms and make some profit out of these delayed sales.
4. **Pay Back Contracts:** Firm agrees to procure a minimum quantity of supplies and the inventory is managed by the supplier. This is termed as vendor-managed-inventory (VMI) with a provision that in case of un-used goods, the firm may pay back to the supplier a certain amount of the total value of un-consumed goods.
5. **Rate Contracts:** The firm fixes a price of supplies and the supplier agrees to supply as and when required at this fixed price. The firm opts for VMI.
6. **Keiretsu Model:** Under this model the firm would enlist suppliers and create a forum of suppliers referred as kankei-kaisha. The parent company may or may not have some stake in the supplier - companies with other commitments such as long term contracts, customised plant investments and or employee co-location. The parent company is tightly integrated with the suppliers, that is, there is continuous buyer – supplier feedback and suggestions to improve operations. The idea is to build long term relationship and not change suppliers unless existing vendors do not show sign of improvements. Under this model the independent firms are referred as dokuritsu-kaisha i.e., outside keiretsu, where parent firm does not have any ownership relationship with these independent suppliers or business partners.

Example 8: Toyota Federation of Suppliers

Toyota has formed a federation of suppliers in line with keiretsu model. Toyota screens suppliers based on its requirements such as quality, reliability, commitment to cost reductions and finally select who are superior in technical innovation, global presence and speed. Toyota would have minority ownership in the supplier – firm and would co-locate its employees in the supplier firms.

Joint Venture

At times when the firms has the capacity to invest but does not have the competence to produce a component or assembly or a product may enter into joint venture contract with suppliers who have the competence but do not have the ability to invest. In such cases the partnership is given a separate legal entity and may be formed under certain terms and conditions. For example, the terms and conditions need to address the questions such as: what would be the equity investment of the companies?; how would cost of operations and revenues shared?; what would be the mode of governance?, and similar issues. An example could be that of Sony-Ericson when Sony, known for its camera technology, co-ventured with Ericson a leading mobile communication company in United States of America, in the year 2001for manufacturing of mobile phones. Later in 2012 Sony acquired the stakes of Ericson and formed Sony Mobile Communications Inc. Here, the contract between the firm and its supplier are not demarcated and both act as one unit. This are also referred as "*Grey-Box*" contracts. A joint venture formed for a specific purpose is termed as special-purpose-vehicle (SPV) or special-purpose-entity (SPE). SPV may get dissolved on fulfilment of the purpose or completion of a project.

Vendor Managed Inventory (VMI)

Under this arrangement, a supplier maintains inventory for a firm without contract or with mutually agreed terms and conditions. The firm provides necessary information to the suppliers, enabling them to maintain and manage inventory. The asymmetry in information provided by the firm may cause stock outs or overstocking. In order to avoid such issues, the suppliers are provided with point-of-sale (POS) data and customer information followed by collaborative forecasting and planning exercises. For example, 7-eleven shares its customer information and sales data with its supplier. Anheuser-Busch (USA) plans its beer sales to 7-eleven based on point-of-sale data. This data not only helps in planning product mix but also cobrand products. Another example of such collaborative planning is the Collaborative-Planning-forecasting-Replenishment (CPFR) system adopted by India's largest car maker, Maruti Udyog Limited (MUL). Some of the company's vendors manages inventory at its own cost at buyer's site. VMI frees the firm from the burden of managing and holding inventory. However, the car makers' interventions are required to ensure uninterrupted supply of *right material at right time at right cost*.

The selection of vendors is made based on their existing capability in terms of volume and variety and their ability to cope up with future requirements. Assessment of future requirements requires the buyer to forecast the trends and develop alternative scenarios which the suppliers need to agree to adopt such changes with or without conditions.

The terms and conditions under VMI may include minimum guaranteed usage by the buyer, pay-back system, cost and revenue sharing by the buyer, equity investments in supplier-firm or simply a rate contract. Rate contract implies that a supplier agrees to supply at a mutually agreed price as and when ordered during a particular period of time, say one year; without any commitment from the buyer.

Material Requirement Planning

Once a firm decides to manufacture certain quantity of product, Material Requirement Planning (MRP) is carried out to determine the inputs required to produce the finished goods. MRP has two primary objectives:

1. Ensure availability of material at the right time
2. Minimize inventory holding cost

The quantity, of items to procure is dependent on the forecast of finished goods. For example a car manufacturer decides to manufacture 10 cars a month as per sales forecast, the number of wheels required would be 5 per car. The time to place order would be the date of fitting wheels minus the lead time to supply the wheels.

Global Sourcing

The cost of item purchased from a foreign source is not limited to ex-factory price or price inclusive of delivery cost. The cost of goods from global sources differs in terms of incoterms (INCO). For example, price may be quoted as 100$ FOB or 110$ CIF or 125$ DDP for the same material. The acronyms such as FOB, CIF or DDP are the INCO terms or the international commercial terms.

INCO terms are shipment terms or terms of trade that primarily defines the responsibility of seller and buyer in international procurements. These terms have been laid down by the International Chamber of Commerce (ICC) so as to harmonize and standardize the terms of trade, across all countries. The description of INCO terms are as:

1. There are 11 INCO terms under 4 categories, namely E, F, C and D.
2. The terms under these categories are:
    a. E category: ExW
    b. F category: FCA, FAS, FOB
    c. C category: CPT, CIP, CFR, CIF
    d. D Category: DAT, DAP, DDP

The descriptions of these acronyms are shown in Table 15.

Thus, the price of an item in global procurement is not relevant without reference to an INCO term. The complete description of an international trade term has at least 5 components, namely, HS code, price, currency, INCO term, and the named place. HS code or harmonised system code describes the material objectively for uniform understanding across countries. It comprises unique 6 digits or more to describe an item. The codes are harmonised up to 6 digits, beyond which it varies from country to country. For example an electronic component or parts has 6 digit HS code as 854290. This code is interpreted uniformly across countries. Further extension of the HS code to say 8 digits are made variedly in different countries to distinguish one electronic part from another. That is, two additional digits are added primarily not only to distinguish the differentiation between two different items under the common category but also to levy different Customs duty for these differentiated items. Countries like Unite States use 10 digit configurations and hence electronic components will have HS code such as 8542.90.00.00. Thus while sourcing we need define "< HS code, price, currency, INCO term, and named place>" so as to specify the item to be procured (HS code),

Table 15.

Sl. No.	Category	INCO Term	Description	Responsibility of Exporter
1.	E	EXW	Ex-works	Exporter provides packed and tested materials at his ware house. All activities export clearance from Customs are done by the buyer.
2.	F	FCA	Free Carrier	Exporter hands over packed and tested materials to the buyer at a dry port or airport or land port after taking clearance from Customs in his country.
3.		FAS	Free Along Side	Exporter hands over packed and tested materials at the loading **sea** port after taking clearance from Customs in his country.
4.		FOB	Free on Board	Exporter hands over packed and tested materials; takes clearance from Customs in his country and puts on board the ship in his country.
5.	C	CPT	Carriage paid to	Exporter hands over packed and tested materials at a dry port or airport or land port after taking clearance from Customs in his country. But he bears the cost of transportation up to a placed suggested by the buyer (named place) in the buyers' country. For example: A sale terms defined as <100$, CPT, Delhi airport> would mean that a foreign seller transfer risk to the Indian buyer in his country but agrees for payment of carriage up to airport Delhi airport, India.
6.		CIP	Carriage and Insurance paid	Exporter hands over packed and tested materials at a dry port or airport or land port after taking clearance from Customs in his country and also bears the cost of transportation and insurance up to a placed suggested by the buyer (named place) in the buyers' country.
7.		CFR	Cost and Freight	Exporter hands over packed and tested materials; takes clearance from Customs in his country and puts on board a ship selected by him, and also pays for shipping freight charges. For example, a seller in Singapore would quote the following price for a buyer in New york as: <100$, CFR, New york seaport>. It means the seller in Singapore transfers the risk to the American buyer in the port in his country after loading the cargo on board the ship, and also agrees to pay the freight up to port in New york.
8		CIF	Cost, Insurance and Freight	Exporter hands over packed and tested materials; takes clearance from Customs in his country and puts on board a ship selected by him, and also pays for shipping freight charges and marine cargo insurance. For example, a seller in Singapore would quote the following price for a buyer in New york as: 105$, CIF, New york seaport.
9.	D	DAT	Delivery at terminal	Exporter hands over packed and tested materials; takes clearance from Customs in his country and delivers the goods to the buyer in the airport or sea port in the buyers' country. For example, a seller in Singapore would quote the following price for a buyer in New york as: 110$, DAT, New york seaport. Note: The cost borne in case of CIF and DAT by the seller is same in both cases, however in CFR or CIF, the risk gets transfer from seller to buyer in the port of seller's country, although he pays for transport freight and insurance up to buyers' port. Whereas in DAT the risk gets transferred to the buyer in the port in buyers' country.
10.	D	DAP	Delivery at place	The seller does all activities and delivers at a named place suggested by the buyer excepting payment of Customs' (import) duties in buyers' country
11.		DDP	Delivery Duty Paid	The seller does all activities and delivers at a named place suggested by the buyer; including payment of Customs' (import) duties in buyers' country. That is, it signifies door-to-door delivery in true sense.

the value of goods (price) in relation with currency in which payment has to be made, the responsibility of the seller (that is, the point where the risk is transferred from seller to buyer, defined through the INCO term) and named place up to which the exporter bears the cost. For example, if the procurement order states as: <8542.90.00.00, 1000 $, FOB, Singapore seaport>, it means the exporter will bear the cost till loading the goods on board the ship at Singapore port. Singapore seaport is the named place. In case of INCO terms under E, F and D category, the named place also refers to the place where the risk is transferred to the buyer. In this example, once the goods are loaded on board the ship at Singapore seaport, the buyer becomes responsible for its delivery up to his destination. In case C category INCO term, the named place refers only to the point up to which the exporter bears the cost. The risk gets transferred, from seller to buyer, at a point before the named place. For example if the procurement orders states as: <8542.90.00.00, 1100 $, CIF, New york seaport>, it means the exporter will bear the cost of loading the goods on board the ship, sea freight and insurance up to New york port, but his risk is transferred at the port of loading, that is, at Singapore port. Hence, it implies that the "named place" may create confusion in terms of trade unless the port of loading is mentioned. The INCO term such as FAS, FOB, CFR and CIF are only applicable when the mode of transport is sea ways. The exporters and importers make mistake using these 4 INCO terms when they use other modes of transport to cross border such as air, road or rail.

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Chapter 5
Multi-Modal Transportation

ABSTRACT

This chapter highlights concepts, dimensions, issues, and challenges associated with multimodal transportation of goods. It gives a decision-making framework for selection of modes and nodes based on the dimensions of multimodal system. Thirteen dimensions of multimodal transportation have been identified and its impact on selection of logistics route has been discussed. A computational framework for selecting the best multimodal route has been proposed in this chapter.

INTRODUCTION

Multimodal transportation refers to movement of cargo by more than one mode of transportation. It is also, commonly, referred as inter-modal transportation. The other references include synchromodal or combined mode of transport (Dua and Sinha, 2018a). Multimodal transportation is interpreted as door-to-door transportation of goods by several modes of transportation with intermodal loading units (Jaržemskiene, 2007). The term *multimodal transportation* assumed significance as shippers and buyers started to demand just-in-time (JIT) and door-to-door delivery. E-commerce led to an integrated and more coordinated multimodal movement of goods. Multimodal transportation in some extant literature is also termed *combined transport*. Intermodal or multimodal transportation may be viewed as an alternative to uni-modal transportation in the case of long travel distances and high volumes of cargo (Bontekoning et al., 2004). Multimodal transportation is said to provide

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an advance platform for efficient, reliable, flexible and sustainable flow of materials in an organisation (Steadie Seife, et. al, 2014).

The choice of modes and nodes in multimodal transfer from origin to destination is based on the trade-off between time, cost and service levels. A shipper expects to meet his 5Rs – Right: form, time, place, practices and price, with regard to delivery of the consignment. The order fulfilment criteria of a firm are best described as "on-time-in-full", or OTIF in short, subject to delivery in right condition (form) following the right practices.

The report implicating Walmart of adopting wrong and un-ethical practices to set up business in Mexico caused uproar and called for payment of penalty of $ 300 million by the US authorities.

The combination of different modes of transportation would depend on 13 dimensions leading to fulfilment of 5R – criteria.

DIMENSIONS OF MULTIMODAL TRANSPORTATION

14 dimensions have been identified based on the literature and field studies. Table 1 illustrates these dimensions.

Cargo Mix Dimension

Cargo can be shipped in three different forms, namely, bulk (loose form), break bulk (packaged form, i.e, in bags, cartons, pallets, drum and in similar way), and as containerised cargo (i.e., cargo put inside containers of standardized sizes). Table 2 provides the description of cargo forms.

Table 1. Dimensions of multimodal transportation

Dimensions of Multimodal Transportation			
1.	Cargo Mix Dimension	8.	Financial Dimension
2.	Modal Mix Dimension	9.	Competition Dimension
3.	Nodal Mix Dimension	10.	Information Dimension
4.	Capacity Dimension	11.	Environmental Dimension
5.	Infrastructure Dimension	12.	Risk Dimension
6.	Demand Dimension	13.	Statutory / Legal Dimension
7.	Quality of Service Dimension	14.	Practices or Ethical Dimension

Source: Authors' creation

In any movement of cargo between origin and destination, the form may be changed in between to meet customers' requirement, minimize cost and or suit the technology and infrastructure available in the transhipment nodes and the end node. Thus, the cargo mix along the multimodal chain will determine the nature of mode and node that forms the multimodal transportation network. The warehousing, storage, material handling equipment and transportation - carriers depend on forms of cargo.

The key characteristics of these forms of cargo are described below.

Dry Bulk Cargo: The cargo which exists in free form and is handled and stowed loose in warehouses and carriers is termed as dry bulk cargo. For example, paddy grains, iron ore or any metallic ores, coal, sand, sawdust, scrap iron, fertilizers, raw material for fertilizers such as phosphates, and sulphur or similar ones can be handled in loose form. Bulk cargo moves by weight. That is, its movement is referred in terms of tons per carrier. This category of cargo has generally low value per unit of weight with low perishability rates. However, different types of cargo would require different safeguards to prevent drop in quality and avoid perishability. For example, contamination of cargo with water (moisture) will have more serious implications for paddy grain than for iron ores. The warehousing, storage, material handling equipment and transportation - carriers associated with dry bulk cargo are described below.

Warehousing and storage: Most of the cargoes in this category are stowed in open yards with exceptions for food grains that are stowed in silos. Grain silos are cylindrical structures connected with conveyors for stowing and removal of cargo.

Equipment: The equipment for handling dry bulk cargo includes:

Table 2. Cargo mix dimension

Category	Description
Bulk	Exists in free form and stowed loose in carriers and warehouses or yards. It can be: i. DDry Bulk or ii. LLiquid Bulk
Break Bulk	Packaged cargo. Stowed and handled in pieces. It can be: i. NNormal or general cargo or ii. OOver Dimensioned cargo or ODC: These are cargo or packages that do not fit into normal or standard size of carriers. It can be over size load or over weight for a normal road or other transport infrastructure; and hence requires special arrangements for movement.
Container	A container is a box with standardized dimensions. It can be road container or marine container or air cargo container. The most common dimensions of a marine container (that moves by ship) are $20' \times 8' \times 8.5'$ (referred as Twenty-Equivalent-Unit or TEU) and $40' \times 8' \times 8.5'$ (referred as Forty-Equivalent-Unit or FEU or 2 TEU).

Conveyors: Consists of belts moving materials between two points, preferably using pulley systems. The conveyors vary in terms of length, speed (ton per hour - tph) and type to suit the nature of materials. The longest conveyor system is seen in Western Sahara connecting the phosphate quarry to the processing plant, which is 98 KM long. The conveyor used in Dubai International airport is 63 Km in length.

Example: a typical industrial conveyor system of 800mm width will have transfer capacity of 140Tons per hour (tph) at a belt speed of 45meters per minute.

Grab cranes: Cranes fitted with grabs for lifting dry bulk cargo and moving to a point of discharge.

Example: A typical grab can have lifting capacity of around 30 tons with volume upto 50 m^3. The cycle time will depend on the radius of the boom that typically ranges from 8 to 38 meters and can have movement ranging from 0 to 90 meters per minute.

Stacker-cum-reclaimers: These are equipment that stock piles dry cargo and enables recovery of the same, fitted with conveyors. This equipment is capable of vertical movement (termed as luffing), horizontal movement (travelling over rail tracks) and rotatory movements (termed as slewing). The capacity of such equipment is also measured in tons per hour (tph).

Example: A typical capacity specification of stacker-cum-reclaimer can be in as:

Table 3.

Stacking	3500t/h
Reclaiming	1500t/h
Slewing Boom Length	60m
Slewing angle	240^o
Rail gauge	8m
Rotation of Bucket wheel	0 ~ 10 r.p.m
Boom Conveyor Speed	250m/min
Luffing speed	5m/min
Slewing speed	0 ~ 30m /min
Travelling Speed	8/25m/min

Transportation

Dry bulk can be moved in trucks, dumpers, rail wagons and ships. It can move in pipeline in form of slurry, if feasible. That is, barring airways, the cargo can be moved in all modes of transport. The carrying capacity varies with mode of transport. Road carriers can take load in the rage of 2 to 40 Tons, while rail carrier can go up to 6000 Tons. Ships, called dry bulk carriers can carry up to 3 hundred thousand tonnes. The weight of cargo loaded in a road carrier or railway wagon is determined by weighing the carrier or wagon over the Weigh Bridge, pre and post loading. Weight of bulk cargo loaded in a ship is determined based on Archimedes' principles. The ship load line prior to loading and after loading is recorded. The difference (increase) in water level reflects the volume of cargo given the cargo surface area of ship. The volume then multiplied with density gives the weight, subject to the position of the ship. If the ship is inclined on any side (front, back, right or left side) the correction factor is applied to determine the actual cargo loaded. There are experts, called draft or draught surveyors to record the change in water level before and after loading in a vessel.

Liquid Bulk Cargo

Cargo that is liquid or gas moved in free form is called liquid bulk. Different types of hydro-carbon oil, chemicals, edible oil, gases such as natural gas fall under this category when it is stowed in tanks and moved by tankers or pipeline. This form of cargo moves by volume. That is, gallons or litres moved per carrier. The loading and unloading is done with pumps and pipes or hoses.

Many of these liquids have properties that can cause hazard to life and property. For example, petroleum products are inflammable while chemicals can be corrosive or gasses can be poisonous. International Maritime Organisation (IMO) has classified hazardous cargo (with IMDG – International Maritime Dangerous Goods code) under nine different classes based on their chemical properties. The warehousing, storage, material handling equipment and transportation - carriers associated with liquid bulk cargo are described below.

Warehousing and Storage: Liquid bulk cargo are stored in tanks that generally cylindrical or spherical in shape, with fixed or floating roofs. Liquids with high flash points, such as fuel oil, water, bitumen and similar, are stored in tanks with fixed roofs. Liquids with low flash points such as ethanol, gasoline, ATF, MS and similar are stored in tanks with floating roofs. Tanks can be over the surface or underground tanks depending on the nature of the liquid.

Equipment: Loading and unloading of liquid cargo is done through hoses connected with the pumps. The hoses differ in terms diameter (say, 2 to 6 inch for loading in to road tankers), vertical motion (say 20^0 to 95^0) and length. The pump capacity is determined in terms of cubic meter per hour (say, 750 m^3 /h for pipeline transfer, 1000 m^3 /h for tank-to-tank blending, 3000 m^3 /h for vessel loading, 300 m^3 /h for truck loading).

Transportation: Liquid cargo can move in tankers on road, rail, waterways and pipeline. The capacity of *road tankers* can range up to 40 KL (kilo-litres). The most common ones fall in the range of 10 to 12 KL, with top loading facility of say, around 1000 LPM (litres per minute). The road-fuel-carriers of higher capacity have bottom loading facility with higher rate of loading, of, say, around 2500 LPM. The tanks on rails have capacity ranging from 40 to 70 m^3 (cubic meter) depending on type of liquid and demand. The smaller ones are preferred for liquid products such as milk while the tanks with large capacity move POL (petroleum-oil-lubricants) products. The crude carrying ships are the largest liquid carriers. The size of the ultra-large-crude-carrier (or ULCC) ranges from 320,000 DWT to 500,000 DWT. DWT stands for deadweight tonnage, it refers to the total carrying capacity of a vessel. That is sum of the weight of cargo, fuel, fresh water, ballast water, crew, and provisions. The standard dimensions of a crude carrier are 415 meters in length, 63 meters in width and require 35 meters draft or draught (or the water level required for ULCC to sail when fully laden with cargo). The next in range is the VLCC (very-large-crude carriers) with capacity between 160,000 DWT to 320,000 DWT. The carrying capacity of tankers or tank ships can be illustrated as described in table 4:

Break Bulk Cargo

This are packaged or general cargo (without packaging for example, machinery) handled in pieces. Sometimes smaller pieces are tied up with pallets for ease of handling. This type of cargo generally possesses high value per unit of weight. Examples of this type includes, drums, barrels, cartons, crates, boxes, machines, iron pipes, logs, steel items and similar. The warehousing, storage, material handling equipment and transportation - carriers associated with break bulk cargo are described below.

Table 4.

Sl.No.	Tanker Type	Carrying Capacity
	ULCC	320000 to 500000
	VLCC	160000 to 319000
	Large Range 2 (LR2)	80000 to 15900
	Large Range 1 (LR1)	55000 to 79999
	Medium Range 2 (MR2)	45000 to 54999
	Medium Range 1 (MR1)	35000 to 44999
	Intermediated	25000 to 34999
	Smaller Tanker	10000 to 24999 DWT

Warehousing and Storage: This type of cargo is stored in covered warehouse of different types. Some materials such as machines may need covered warehouses to protect from sun and rain. On the other hand some packages may need protection from humidity as well. Cargo such as food items or medicines may require temperature controlled warehouses.

Equipment: The packages of smaller dimensions and lesser weight, i.e., within 10 tons are moved using forklifts and loaded or unloaded using cranes. Automatics guided vehicles (or AGV) are used for handling off-shelf materials in warehouses. They can lift, rotate and shift goods as driverless fork lifts. Unmanned aerial transport system or drone transports are also being introduced to move goods, by companies such as Amazon. Heavier cargo or over-dimensioned cargo (ODC) is handled by heavy lift cranes depending on the weight of package or material.

Transportation: Road **c**arriers of break bulk cargo include parcel vans, trucks, trailers, and railways. Railways provide different type wagons – closed, flat rake, open wagons. Break bulk cargo with high value – volume ratio is best suited for air movement, as it ensures faster delivery and shorter cash-to-cash cycle. In maritime shipping break bulk cargo move by general cargo vessels. The capacity of break bulk vessels are low as in many cases cargo are move in containers. Majority of the break bulk movement include ODC and vehicles. ODC include project cargo, machines, logs, steel items such as pipes. There are designated carriers for logs, steel items, project cargo and similar. These carriers carry only a single type of cargo in full-ship-load mode. This mode of transportation of full shipload of a particular cargo is termed as neo-bulk cargo movement. For vehicles there are auto carriers only meant to carry automobiles. In such vessels automobiles are driven inside the ship, where the ships are called Ro-Ro (roll-on & roll-off) carriers. There are instances where a trailer loaded with break bulk cargo (generally ODC) move inside the vessel and the cargo gets transferred along with the trailer. This also falls under Ro-Ro movement. Cargo loaded on board the ship with cranes are referred as lo-lo (lift on & lift off) cargo while cargo driven in vessels are called Ro-Ro cargo.

Containers

These are boxes of certain standard dimensions. The most common dimensions that move by ships are 20′ × 8′ × 8.5′ (1 TEU or twenty equivalent unit) and 40′×8′×8.5′ (one forty equivalent unit – FEU or 2 TEU). Certain containers have height of 9.5 feet′ (in lieu of 8.5 feet) and are called "High- Cube" containers. These dimensions have been standardized by International Standard organization (ISO). However, various other types of containers also exist. These are commonly referred as marine containers. In maritime container shipping set of terms such as FCL or CL; and LCL are used. CL stands for container load and has same meaning as that of FCL or full container load. These are containers, of any particular dimensions, stuffed with cargo belonging to a single shipper. LCL (or less-than container load) containers carry consignments of different shippers in a single container.

Containers that carry air freight are called Unit Load Devices (ULD) and are of varied sizes. Containers are generally made up of steel or aluminium. Filling of containers with different goods is called "stuffing" while removal of goods from inside the container is called "de- stuffing" or "de-vanning".

The warehousing, storage, material handling equipment and transportation - carriers associated with containers are described below.

Warehouse and storage: Containers are stored in open yards as containers are robust enough to protect cargo from climatic forces. The stuffing and de-stuffing of packages to and from containers are done inside a container freight station. On completion of such operations containers are stored in yards. The insulated or refrigerated containers (also referred as reefer containers) have provisions to draw power in the yard. The containers are stowed one top of the other in yards. The stack height or number of containers that can be put in stack depends on the strength of the container yard and the equipment used to handle containers in yards.

Container yards are generally divided into blocks separating 20 feet container loaded and empty; 40 feet containers loaded and empty; and space earmarked for other types on container and reefer containers. In ports separate portions are earmarked as export and import containers respectively.

Equipment: Containers are stuffed and de-stuffed with forklifts. Container handling equipment in yards include rail mounted gantry cranes (RMG), rubber tired gantry cranes (RTG), reach stacker (RST), straddle carriers (SC) and similar variants. These equipment have same lifting capacity but vary in terms of speed (cycle time), stacking height, reachability and manoeuvrability. RMG and RTG have higher speed, can stack more than 4 high containers, but their manoeuvrability is limited by tracks on which it moves. RST have greater manoeuvrability but can stack only up to 4 high. Besides, its reachability is restricted to front row of containers. Straddle carriers can stack up to 3 high but have higher manoeuvrability as it can transport containers from yard to berth.

Transportation: On roads containers move on trailers while on trains it is put on flat wagons. A container carrying ship is called a cellular ship. Sometimes containers are also moved along with other type of cargo especially in break bulk vessel. In such cases they are stowed on the weather deck while the major cargo is stowed in the ship's hold.

MODAL MIX DIMENSION

There are five modes of transportation namely, road, rail, water, air and pipeline. The choice of modes of transportation would depend on 6 factors, namely:

1. Type of packaging
2. Shape and Size
3. Weight and Volume
4. Distance
5. Transit and Delivery Time Variability

Road carriers are best suited for inland transportation and enables door to door movement. The parcel load per carrier is limited to 80 tons. In some cases, multi-axle road carriers can take load up to 120 Tons. A rail carrier can hold 40 to 60 Tons per wagon, and rake or a train can attach 40 to 60 wagons. Hence, the carrying capacity of rail carrier ranges from 2000 to around 4000 Tons with certain exceptions. Ships have varying range of carrying capacity depending on type of cargo. For example, capacity of crude carriers can be up to 500,000 Tons while capacity of dry bulk carrier can be up to 300000 Tons. In planning for multimodal movement of goods the carrying capacity constraint of various modes of transportation need to be borne in mind. In case of transfer of goods from modes with lower capacity to mode of transportation with higher capacity, time to build up inventory and time to for load onto higher capacity carrier affect the dwell (stay) time of cargo. There should be commensurate storage facilities in the terminals.

For example, coal moved by dumpers from mines would move overseas by sea. Dumper, typically have capacity to carry 40 Tons. The sea carrier with say 40000 Tons capacity would require 1000 dumper-movement. If per day 500 dumpers can arrive at the port, it will take 2 days to build up the inventory of 40000 Tons. The port should have storage capacity of at least 40000 Tons. If loading rate on board the vessel is 20000 Tons per day, the ship would stay at berth for 2 days. The storage requirement can be reduced if coal is loaded directly from mines by conveyors on board the vessel. In such case the stay time of ship at berth would depend on loading rate by conveyors. If a conveyor has loading rate of 120 tons per hour, the ship will approximately have 14 hours stay at berth.

The time to build inventory and storage capacity can be reduced by means of direct delivery onto the carriers especially for containers. Containers that are cleared for exports by customs authority at the factory or at dry-ports can be allowed to directly move up to the berth for loading on the ship. This will save time as containers need not be unloaded and stacked in export yards followed by transfer by trailers to the berth.

The time to move containers on board a vessel can be further reduced if containers move as a Ro-Ro cargo. Such Ro-Ro container vessels have less capacity in terms of number of containers it can take on board compared to the cellular vessels.

Similarly, when goods move from carriers of higher capacity to carriers with lower capacity, stock piling at terminals such as ports becomes necessary for further clearance by low haulers.

Thus, capacity of different carriers and mode of transfer from one carrier to another becomes deciding factor on the capacity of warehouses and equipment fleet strength.

For example, if a firm in eastern part in India has bagged an order for supply of 15 tonnes of paddy rice in 25 kilo packs to a firm in Gabon (west Africa), the different options available for the Indian firm includes:

Option 1: Paddy rice shipped as **dry bulk cargo** from rice fields to a sea port by road carrier (trucks) and stored in silos in the port. From silos in port paddy rice is loaded on to a dry bulk carrier of 20000 DWT that moves directly from port in India to port Libreville in Gabon. At port Libreville paddy grains are **bagged** in 25 kilo bags and moved by road to the buyer. This option assumes that there is bagging facility at port Libreville.

Option 2: Paddy rice shipped as **dry bulk cargo** from rice fields to the port by road carrier (trucks) and stored in silos in the port. From silos in port paddy rice is **bagged** and bags are loaded on to a general cargo carrier of 20000 DWT, as full ship load cargo. This carrier moves directly from port in India to port Libreville in Gabon followed by road transportation of the bagged rice to the ultimate buyer. This option assumes that there is bagging facility at port in India.

Option 3: Paddy rice shipped as **bagged cargo** from rice fields to the port by road carrier (trucks) and stored in covered warehouses in the port. These bags are loaded on to a general cargo carrier of 20000 DWT, as full ship load cargo. This carrier moves directly from port in India to port Libreville in Gabon followed by road transportation of the bagged rice to the ultimate buyer.

Option 4: Paddy rice shipped as **bagged cargo** from rice fields to the ports by road carrier (trucks) and stuffed in **containers** in a dry port (inland container depot - ICD or container freight station - CFS). These containers move by road trailers to ports and stored in container yards. These containers are loaded on to a container vessel as liner cargo. These containers move via transhipment ports instead of moving directly from port in India to port Libreville in Gabon.

The options available differ in terms of time and cost. The objective of multimodal logistics planning is to minimize the total cost of operation (TCO) subject to the time constraint. That is, it can be mathematically expressed as:

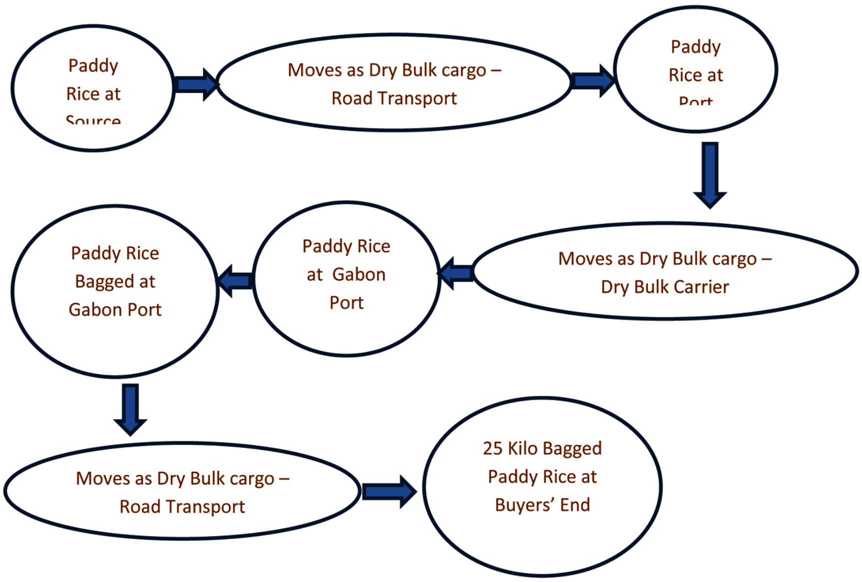
$$\text{Minimize } Z = TCO \qquad (1)$$

Equation 1 implies that the cost of logistics (Total-cost-of-operation: TCO)) is minimized subject to given constraints.

That is, subject to the following constraints:

$$T_{Dm} \leq C_D\ ; \qquad (2)$$

Figure 1. Nodes and modes of transportation in option 1



Equation 2 is a constraint; it prescribes that time to deliver by different modes of transport should meet time stipulated by the customer

$$C_{T1} \leq C_D \leq C_{T2} \tag{3}$$

Equation 3 is a constraint; it prescribes that time to delivery should be within a given time window, i.e., neither too early (greater than C_{T1}) nor beyond the stipulated time (less than C_{T2})

$$T_D, C_{D,} C_{T1}, C_{T2} \geq 0 \tag{4}$$

where:

T_{Dm}: Time to Deliver

C_D: Customer's Stipulated Time

C_{T1}: Time before which supply not to be made

C_{T2}: Time beyond which supply not to be made

The above formulation is suited for a single mode of transport between origin and destination, assuming that the cost incurred at the two nodes are not significant compared to mode of transport and hence can be neglected. However, for multimodal transportation more than two nodes are involved and the decision model need to be formulated as described in next section.

Tonneau et al, (2015) formulated a two-stage model for optimization of multimodal transportation.

In the first stage it chooses the best mode of transportation considering the following factors:

Time to move cargo
A distance cost C_d^m
A time cost C_t^m
A pickup Tp^m and a delivery Td^m time (in hours)
A volume capacity Vmax ^{m} (in m^3)
A weight capacity Wmax ^{m} (in tons - t)
A speed v^m (in km/h)

The cost $C_{i,j}^p$ associated with product p having a density ρ^p (in t/m^3) for a given distance $d_{i,j}$ is expressed as:

$$\frac{C_{i,j}^{\ p} = min \quad C_k^{\ m} + \left[Tp^m + Td^m + \left(d_{i,j} \div v^m\right)\right] C_h^{\ m}}{Min(Wmax^m, \ (r^p * Vmax^m)} \tag{1}$$

Equation 1 leads to the choice of the best mode of transportation. Once the best mode of transportation is chosen, the authors suggest optimization of cost in the second stage. That is;

Objective function:

"Minimize cost of moving the goods p, of quantity $x_{i,j}$, from node i to j ($C_{i,j}^p$)"

In case a transformation of product p is required at node i, the cost of transformation ($C_{i,}^t$) is also considered in this model. $y_{i,}^t$ is the extent of transformation of product p or the transformation quantity. The transformation can take place in more than one intermediary node. It can be considered as transhipment cost as well. For example, paddy rice in industrial bags of 100 Kg moves in containers. The containers from an Indian ports moves to port in Gabon via transhipment port of Colombo (a first level of transformation having a cost element). At port in Gabon, the rice is repacked in 25 Kg packs – a second level of transformation having a cost element. The objective function can be re-written as:

Minimize

$\sum (C_{i,j}^{p})\, x_{i,j} + \sum \sum (C_{i,}^{t})\, y_{i,}^{t}$

Subject to:

Delivery demand, flow quantity ≤ production quantity

Storage capacity, transit capacity ≥ flow quantity

Cargo flow from origin = Cargo demand at destination (final customer)

And other constraints associated with a convex set.

The above model is applicable for a uni-modal transportation of cargo. That is, after the choice of the best mode is made, the mode (of transportation) remains unchanged. Besides, a mode of transportation has the option to originate and terminate at different terminals. For example, a shipper, for sea mode of transportation) may choose port A over port B for shipment. Similarly, there may be options available to choose intermediary and destination ports. These choices are made by shippers and carriers based on cost, timeliness, efficiency and other quality factors. This aspect has not been considered in this approach.

NODAL MIX DIMENSION

Nodes refer to warehouses and terminals from where goods originate, gets transhipped and discharged. This dimension relates to number and type of nodes in multi-model transportation to be traversed under different options. The nodes vary in terms of efficiency and cost of operations at nodes. After loading at source node, goods can pass through gateway terminals and or hubs, before it reaches the final destination. The change in modes of transport happens in gateway terminals. In case of non-availability of direct voyage between terminals to the next node of transfer, the good move via hub ports. This is especially observed in container shipping. Hubs are transhipment points. In absence of direct connectivity between two nodes, gateway terminals or hubs play an important role in sending goods between any points in the world. At the same time, addition of a node in the route increases time, cost and enhances the probability of damage and loss.

In planning of multimodal logistics, the choice of cargo mix and its corresponding mode of transport become important to minimize time and cost.

For example, if paddy rice, in example above, moves as per option 1, 2 and 3, the number of nodes are less compared to option 4.

Thus, in cases where goods move in trunk route i.e., hub to hub; or along direct feeder routes, i.e., spoke to spoke, time taken is less compared to spoke – hub – spoke model, or spoke –hub – hub –spoke model.

The decision model can be restated as:

$$\text{Minimize } N \quad (5)$$

where N is number of nodes;

Equation 5 implies that we need to minimize the number of nodes so as to reduce risk of delay, cost and damages subject to certain constraints.

Subject to

$$TCO \leq Z \quad (6)$$

Equation 6 implies that the total-cost-of-operation (TCO) should be less than Z or targeted expenditurewhere $TCO = \sum CN_i + \sum CN_{ij}$ (7)

Equation 7 implies that the total-cost-of-operation (TCO) is equal to the cost at each node i (CN_i) and cost to move goods between node i to j (CN_{ij}).

$$\sum TN_i + \sum TN_{ij} \leq C_D \quad (8)$$

where TN_i is the time spent at node I and TN_{ij} is the time to travel from node i to node j;

Equation 8 implies that the delivery should be made within the stipulated time window.

INFRASTRUCTURE DIMENSION

This dimension refers to impact of terminal infrastructure, route conditions and regulatory mechanism on multimodal transportation of goods. The quality of infrastructure of terminals, roads and highways, railway tracks, and the regulatory mechanism influences the time taken in movement of goods from one node to another. The performances of terminals are determined by dwell time of cargo in terminals such as ports and turnaround time (TAT) of carriers, say ships. Poor infrastructure in ports causes TAT and dwell time of cargo to increase, thus reducing the market shelf of goods. The conditions of routes are reflected in terms of speed a carrier can achieve. In developing and less developed countries bad road conditions slows down movement of goods, leading to increase in transit time. Inconsistent regulatory mechanism, especially those which are not automated, cause delay. The toll gates and check posts on highways slow down movement of goods. In many countries frequent checks of cargo carried on road carrier increases cost and time.

The TAT can be expressed as:

$$TAT = \sum(W_t + IM_t + O_t + NO_t + OM_t) \quad (9)$$

where:

W_t: Waiting time of carrier to secure position for unloading and loading operation. For example, a ship waits to get a berth or a jetty or any similar operating point. Waiting time is a function of document clearance time and availability of number of working points. For example, a ship before getting permission to enter a dock has to submit documents and clear all formalities that delays entry unless the same is done in advance, that is, prior to arrival of a ship.

IM_t: This denotes the inward movement time, that is, after the carrier has reported its arrival at the reporting point of a terminal or node. This time starts after the waiting time is over and the carrier proceeds to the operating point. In such cases, the carrier may face queue or congestion or delay in getting clearances at gate or any inward entry point. In case of ships, the carrier has to be towed with help of tugs in the navigable channel leading to the dock and finally berthed under port-marine supervision. In some cases such as port of Kolkata in eastern part of India, the navigational channel is 230 Km long from the point ship reports to the port. The ship in the entire stretch is guided by vessel-traffic-management system, ports own pilot who go on board the ship in the midstream (using rope ladders) and tugs with masters of tugs guiding the vessel to the berth. The entire operation takes almost half a day. Besides, the port of Kolkata being a river based port depends heavily on tides to bring fully laden ships. Thus ships enter or leave during high tides that cycles every 12 hours. So if by any reason the tide is missed, the ship has to wait for another 12 hours leading to increase in TAT. Inward movement of carrier (IM_t) differs on account of distance of navigable channel, and efficiency of ports' marine system.

O_t (Operational time): This denotes the carriers' working or operational time in a node. That is, the time it takes to unload and load goods. This is the carriers' productive time spent in a node or a terminal. O_t is function of parcel load (the load it unloads and / or loads); and productivity of the node. That is:

O_t = (Goods unloaded + Goods loaded) ÷ moves per hour

Moves refer to number of packages or containers or tons of cargo unloaded or loaded per hour.

NO_t (Non-Operational time): This to the time lost after start of operation may be due to weather conditions, strikes, equipment break down, non-availability of resources or lack of coordination.

OM_t: This denotes the outward movement time after completion of unloading and loading operations. A carrier may be required to wait due to congestions and queue in exit points and or for completions of document clearance by the terminal and other statutory authorities. In Customs bonded nodes, Customs take time to accord permission to take the goods out of the node. Sea ports, dry ports (inland container depots and container freight stations), air ports or bonded warehouses are examples of Customs bonded nodes. This primarily affects the competitiveness of export and import cargo.

A logistics manager should choose a node where TAT of carrier and dwell time (DT) of cargo is lower. Dwell time refers to the time cargo is stored in a port or terminal before loading or after discharge.. For example a consignment needs to be brought to a sea port for exports, say 7 days prior to the arrival of ships. On arrival of ship cargo is loaded on board the vessel and the cargo waits on board till the it leaves. Thus, time spent at node (TN_i) is equal to:

$$TN_i = DT + TAT \quad (10)$$

CAPACITY DIMENSION

The number of highway lanes, wagons per rakes, available navigable draft and load bearing capacity of the rail-road-sea routes affect movement of cargo. Quantum of cargo moved per unit time increases with increase in capacity. Besides, storage and material handling capacity of terminals would also determine the choice of node and mode of transport. Material handling capacity refers to unit load per equipment per move and the cycle-time per move. Higher the load bearing capacity and quicker the cycle-time, faster is the loading and unloading of cargo.

Thus capacity of terminal can be computed as:

$$N_C = N_o \text{ x } O_p \text{ x } P \text{ x } N_d \quad (11)$$

where:

N_C = Capacity of a node to handle goods
N_o = Number of Operating Points
O_p = Percentage Occupancy of an Operating Point
P = Productivity (moves per day)
N_d = Number of days terminal is functional in a year.

For example, if a marine container terminal has 3 berths with 1000 moves per day (i.e., 40 moves per hour of a 20 feet ISO containers) per berth with each berth having 70% occupancy out of 300 operational days in a year; the terminal has an annual capacity of:

[3 x 1000 x 0.70 x 300] = 6, 30,000 containers (in TEU)

Equation 11 assumes that storage or yard space do not pose constraint to the capacity of the node. If it does, then the throughput of terminal needs to be computed as:

$$T_r = [G_s \text{ x } S_h \text{ x } N_d] \div DT$$

where:

Tr = Throughput of a terminal
Gs = Ground slots
S_h = Stacking Height

For example, the container terminal has 2000 ground slots with stack height of 4 containers; dwell time (DT) of 5 days, and N_d = 300 days, the annual throughput is equal to:

(2000 x 4 x 300) / 5 = 4, 80,000 containers.

Hence, the capacity of the container terminal is constrained by container yard capacity and dwell time. If the dwell time is reduced to 3.8 days then the port capacity would match yard capacity and the storage would not acts as a constraint.

For loose cargo, such as coal, the stack height needs to be replaced with tons stored per unit slot.

FINANCIAL DIMENSION

The cost of multimodal logistics incorporates fixed and variable cost, penalties, delays and opportunity cost. For certain modes of transport, fixed cost may be higher with very low variable cost or vice versa. For example, the agency cost for sea transport may be higher, while variable cost (per ton) in sea transportation may be lower compared to air transportation. Similarly, the insurance cost in air transport is less compared to movement by sea transport. The variability in performance of certain modes of transport may lead to variability in delivery time, thus causing penalties and opportunity cost to go up. Besides, for a given mode of transport, the performance of the transport providers may not be consistent, leading to increase in cost as well. Thus, the total cost of operation includes:

$TCO = \sum (Fc + Vc + Lc + Pc + Dc + Oc)$;

where

Fc = Fixed cost

Vc = variable cost (in terms of type of cargo, quantity or volume of cargo and distance to be moved): Inland freight + Terminal handling Charges + Sea or Air freight + Cargo Insurance + Export Credit Insurance Cost + Inland freight in importers country + Terminal handling Charges in importers country + Customs Duty + Taxes

Lc = Land Side Cost: Charges levied by shipping lines on arrival of cargo such surcharges on account of congestion, foreign exchange fluctuations, damage to containers or on similar account.

Pc = Penalty: Charges paid to agencies and authorities due to non-compliances and delays

Dc = Demurrage Cost: Charges paid to terminals such as ports or agencies such as shipping lines when importer has not taken clearance of cargo or removed the cargo within the free time provided by the port or shipping line or the charterer has exceeded the free time provided by the shipping line.

Oc = Opportunity Cost: The loss of good will and lost sales arising non-fulfilment of customers' needs.

DEMAND DIMENSION

The supply of material to the consignee can be on one-time basis or phase wise in a given period of time.

For example, one million metric ton (MMT) of cargo is required to be shipped as a one-time requirement vis-à-vis 1MMT of cargo to be shipped in phases comprising 40,000MT per shipment every 20 days. In the first case a single shipment of 1MMT is the best choice. However due to restrictions imposed by the draft and infrastructure at loading and or unloading port, the number of shipments will increase.

In the latter case, a smaller ship with carrying capacity 40000 MT of cargo each time is the best choice. In this situation minimum 3 shipments (of 40000 MT per shipment) are required. As the shipment size is less the draft requirement is also lower and availability of ports increases. For example most (out of 200) of the ports in India have draft of 10 meters or less. These ports cannot accommodate cape size vessels.

The multimodal logistics planning gets influenced under these two scenarios. In case of one time shipment, the choice of modes of transportation, carriers and nodes gets restricted. The requirement for larger carriers and nodes to accommodate such carriers (mega-terminals) becomes important. Availability of such nodes reduces. On the other hand, when the size of consignment per shipment is lower, more options on terminals and service providers are available.

QUALITY OF SERVICE DIMENSION

A shipper may take responsibility of shipment from his end to any point in the logistics chain. It can be door – to – door, or door – to – port in importers' country or up to any other point. This can be understood in terms of international commercial terms (INCO terms) applicable in global trade. There are eleven shipment terms under INCO terms 2010. These are categorized under 4 categories, namely, E, F, C and D. Under E and F category, the responsibility of an exporter ends in his own country. The responsibility under C category is same as that of F category INCO terms except that exporter bears the logistics cost up to a named place in importers' country. Thus the quality of service is restricted up to a point in the sellers' country, say, a dry port, sea port or airport. Thus under C category, the exporter exercises control on cost but not on the quality of delivery (service). Under D category INCO term, the responsibility of exporter extends up to a named place in importer's country and can be door – to –door with or without payment of import duty. Here the seller exercises control the quality of service.

COMPETITION DIMENSION

Cost of multimodal transportation of goods decreases the competitiveness of goods. The cost of logistics is primarily dependent on two factors; one, the fuel cost and second, the number of (logistics) service providers i.e., the supply-demand gap. In a monopoly or oligopoly market the cost of logistics is higher. In such cases shipper has less choice of service providers and has to depend what the service providers provide. In a monopsony market a shipper has wider choice at lower cost.

INFORMATION DIMENSION

Visibility is an important aspect in multimodal movement of goods. Availability of right information at right time aids in proactive decision making. Off line information makes tracking and tracing of cargo difficult, and thus reduce control on logistics activities resulting in increase in risk and uncertainty. On the other hand on-line systems enable data capture at the point-of-operation enabling implementation of integrated logistics system. On-line systems with in-built time constraints resulting in instantaneous capture and availability of information, is called real-time system. It requires implementation of highly automated systems such as RFID, GPS, camera based data capture etc. where in there is data capture simultaneously along with the event. For example, use of hand-held-terminals to record position of containers in a yard at the time of their movement is an example of on-line system, while use of radio-frequency-identification (RFID) system to record such movement is an example of a Real Time system. Integration of real time systems with data analytic systems enables creation of artificial intelligence leading to better decision making; and helps in reducing variability in transit and delivery time. Multimodal systems equipped with such technology are preffered over others.

RISK DIMENSION

Bichou (2015) suggested that the main risk factors and security threats related to ports need to be identified and analysed. Besides, terrorism and piracy at sea has been constant threat to shipments over Indian and Atlantic ocean (Rodrigue, 2004; Bueger, 2015). Germond (2015) showed that there is a geopolitical dimension of maritime security and need inclusion in developing security strategies. Bueger (2015) suggested frameworks on maritime security. He stated that four concepts, namely, marine safety (terrorist acts, piracy, accidents and pollution), seapower (inter-state disputes, arms proliferation), blue economy (food security, smuggling) and human resilience (illegal, unreported and unregulated fishing; piracy) are primary to the understanding of maritime threats.

The direct impact of risk is felt from the cargo insurance cost levied by cargo insurers. Cost of air cargo insurance is less than maritine cargo insurance for a given type of material, quantity and distance.

LEGAL / STATUTORY / ENVIRONMENTAL DIMENSION

The choice of mode of transport and their inter operationability also depends on the legal, statutory and other environmental factors. The stringent and ambiguous legal system acts a non – tariff barrier to trade. The timings restriction on movement of goods vehicles in cities causes longer transit time for nodes within city limits. Countries also have restrictions in use of certain packaging materials such as wood. There are restrictions imposed on carriers with emission above certain levels and with regard to transport of hazardous cargo. These aspects need to be borne in mind while planning for multimodal movement of goods.

PRACTICES AND ETHICAL DIMENSION

Multimodal transportation in international business involves interaction with stakeholders from different countries. Some of the countries are yet to frame up the right practice codes and as such incidents of bribery, child labour, stowaways and mis-information are reported even in developed countries (Presidia Security Consulting, 2011).

The Multimodal Planning: Computational Model

Multimodal logistics planning begins with identifcation of customer requirement, best described in terms of 5 Rs – Right form, Right place, Right time, Right practices at Right price. Given these requirements, the logistics planner needs to optimize the cost, following the right practices. In the process of optimizing the cost, the planner needs to identify the plausible cargo mix that meets the customers requirement. Based on the different options, in terms of a cargo mix (bulk – break bulk – container), the different modal mix is identified. The nodes are selected based on factors namely, productivity, variation in cost, complexities in procedures and documentations, communication effectiveness, collaboration and coordination; as these affect the quality of multimodal transpoartation (Dua and Sinha, 2018b). Subsequent to this step the route selection is done subject to fullfilment of criteria laid down by customer and the cost that is confined below the price that the logistics services offered to the customer.

The steps in multimodal route selection include:

1. Identify the set of routes (r_i), i = 1,2, 3………r
2. For every route identify the set of modes (m_{ijk}) between node j and k.
3. For every route identify the set of nodes (n_{ij}), j=1,2,3………..k
4. For every node determine the values of:
    a. Dwell Time for node n_{ij}, that is jth node in route i; $\mathbf{d_{ij}}$
    b. Terminal Chandling Charges for node n_{ij}; $\mathbf{h_{ij}}$
    c. Agency cost for node n_{ij}; $\mathbf{a_{ij}}$
    d. Damage rate or loss rate for node n_{ij}; $\mathbf{l_{ij}}$

e. Agency Rating for node $n_{ij,}$ that is, competence of agency $\mathbf{r_{ij}}$
f. Customization options availability for node n_{ij}, $\mathbf{c_{ij}}$
g. Procedure and Documentation complexity for node n_{ij}; $\mathbf{p_{ij}}$
h. Communication system (technology) availability for node n_{ij}; (Real time / on line / batch), $\mathbf{t_{ij}}$
i. Variability in terminal performance (error rates) for node n_{ij}, e_{ij}

5. For every mode determine the values of:
   a. Transit Time for mode m_{ijk}, $\mathbf{T_{ijk}}$
   b. Freight for mode m_{ijk}, $\mathbf{F_{ijk}}$
   c. Damage rate or loss rate for mode $m_{ijk,}$ $\mathbf{D_{ijk}}$
   d. Time Variability for every mode, $\mathbf{V_{ijk}}$
   e. Customization options available for mode $m_{ijk,}$ $\mathbf{C_{ijk}}$
   f. Procedure and Documentation complexity for mode $m_{ijk,}$ $\mathbf{P_{ijk}}$
   g. Communication system availability for mode $m_{ijk,}$ $\mathbf{S_{ijk}}$

6. For every node compute standardized score as sum of the following:

Node Score (NS)= $\sum\{[1/(\mathbf{d_{ijq}})_s] + [1/(\mathbf{h_{ijq}})_s] + [1/(\mathbf{a_{ijq}})_s] + [1/(\mathbf{l_{ijq}})_s] + [(\mathbf{r_{ijq}})_s] + [(\mathbf{c_{ijq}})_s] + [1/(\mathbf{p_{ijq}})_s] + [(\mathbf{t_{ijq}})_s] + [1/(\mathbf{e_{ijq}})_s]\}$;

where:

a. Dwell Time Score for node n_{ijk}: $(\mathbf{d_{ijq}})_s = \mathbf{d_{ijq}} / (\mathbf{d_{ijq}})_b$;

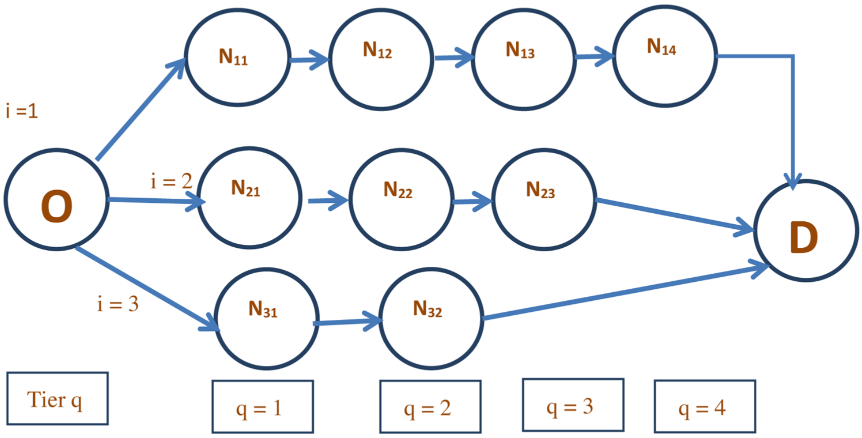
where $(\mathbf{d_{ijq}})_s$ **= standardized score of** $\mathbf{d_{ijk}}$**;**$(d_{ijk})_b$ is benchmark value of d_{ijq}.

The benchmark value can be the lowest $\mathbf{d_{ij}}$ in tier "q" of the multimodal network. For example: If there are 3 routes available, i.e., i = 3, the minimum of dwell time $\mathbf{d_{ijq}}$**, That is,** Min{for i = 1, j =1 and q=1; for i = 2, j =1 and q=1; for i = 3, j =1 and q=1}; OR, it can be a desired value assigned by the shipper.

b. Terminal Chandling Charges (THC) Score for node n_{ij}: $(\mathbf{h_{ijq}})_s = \mathbf{h_{ijq}} / (\mathbf{h_{ijq}})_b$ **; where** $(\mathbf{h_{ijq}})_s$ **= standardized score of** $\mathbf{h_{ijq}}$**;** $(\mathbf{h_{ijq}})_b$ **is benchmark value of** $\mathbf{h_{ijq}}$**.** for node n_{ijq};

The benchmark value can be the lowest $\mathbf{h_{ij}}$ in tier "q" of the multimodal network. For example: If there are 3 routes available, i.e., i = 3, the minimum THC $\mathbf{h_{ijq}}$**, That is,** Minimum of **{THC** for i = 1, j =1 and q=1; for i = 2, j

Figure 2.



=1 and q=1; for i = 3, j =1 and q=1}; OR, it can be a desired value assigned by the shipper.

c. Agency cost Score for node n_{ij}; $(\mathbf{a}_{ijq})_s = \mathbf{a}_{ijq} / (\mathbf{a}_{ijq})_b$ **; where** $(\mathbf{a}_{ijq})_s$ **= standardized score of** $\mathbf{a}_{ijq}$**;** $(\mathbf{a}_{ijq})_b$ **is benchmark value of** $\mathbf{d}_{ijq}$**.**

The benchmark value can be the lowest $\mathbf{a}_{ij}$ in tier "q" of the multimodal network. For example: If there are 3 routes available, i.e., i = 3, the minimum agency cost a_{ij}**, is,** Min{for i = 1, j =1 and q=1; for i = 2, j =1 and q=1; for i = 3, j =1 and q=1}; OR, it can be a desired value assigned by the shipper.

Figure 3.

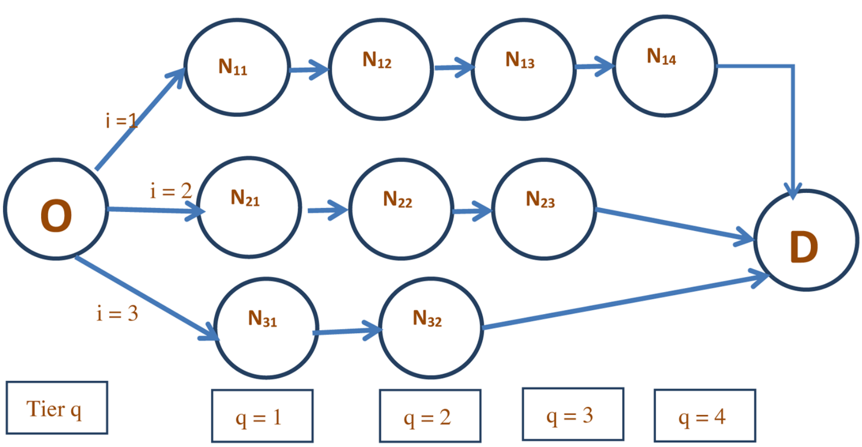
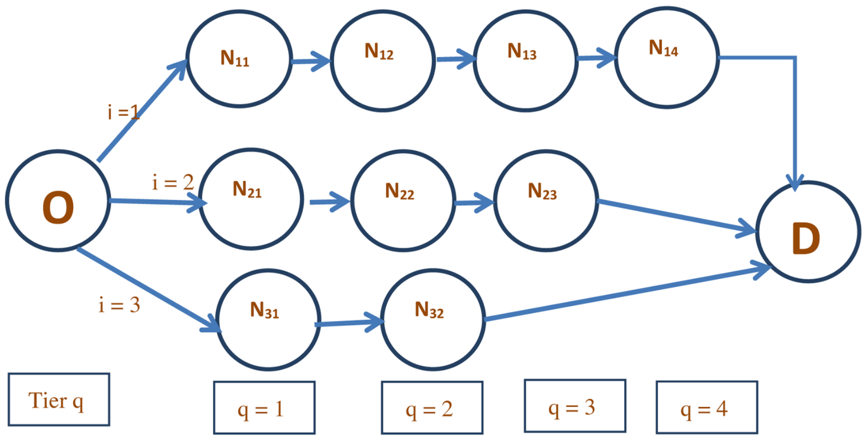


Figure 4.



d. Damage rate or loss rate for node n_{ij}; $(l_{ijq})_s$ = $\mathbf{l_{ijq} / (l_{ijq})_b}$ **; where** $(l_{ijq})_s$ **= standardized score of** $\mathbf{l_{ijq}}$**;** $\mathbf{(l_{ijq})_b}$ **is benchmark value of** $\mathbf{l_{ijq}}$**.**

The benchmark value can be the lowest $\mathbf{l_{ij}}$ in tier “q” of the multimodal network. For example: If there are 3 routes available, i.e., i = 3, the minimum loss rate $\mathbf{l_{ij}}$**, That is,** Min{for i = 1, j =1 and q=1; for i = 2, j =1 and q=1; for i = 3, j =1 and q=1}; OR, it can be a desired value assigned by the shipper.

e. Agency Rating for node n_{ijq}, that is, competence of agency, $(\mathbf{r_{ijq}})_s$ **=** $\mathbf{r_{ijq} / (r_{ijq})_b}$ **; where** $(\mathbf{r_{ijq}})_s$ **= standardized score of** $\mathbf{r_{ijq}}$**;** $\mathbf{(r_{ijq})_b}$ **is benchmark value of** $\mathbf{r_{ijq}}$**.**

The benchmark value can be the highest $\mathbf{r_{ij}}$ in tier “q” of the multimodal network. For example: If there are 3 routes available, i.e., i = 3, the maximum rating $\mathbf{r_{ijq}}$**, that is,** Max{for i = 1, j =1 and q=1; for i = 2, j =1 and q=1; for i = 3, j =1 and q=1}; OR, it can be a desired value assigned by the shipper.

f. Customization options availability at node n_{ijq}, $(\mathbf{c_{ijq}})_s$ = $\mathbf{c_{ijq} / (c_{ijq})_b}$ **; where** $(\mathbf{c_{ijq}})_s$ **is standardized score of** $\mathbf{c_{ijq}}$**;** $\mathbf{(c_{ijq})_b}$ **is benchmark value of** $\mathbf{c_{ijq}}$**.**

The benchmark value can be the highest customization options c_{ij} in tier “q” of the multimodal network. For example: If there are 3 routes available, i.e., i = 3, highest customization options c_{ij}**, That is,** Max c_{ij} {for i = 1, j =1

Figure 5.

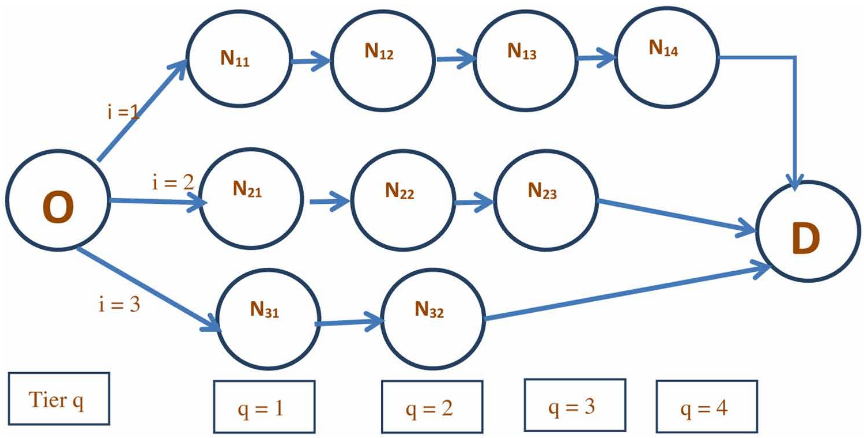
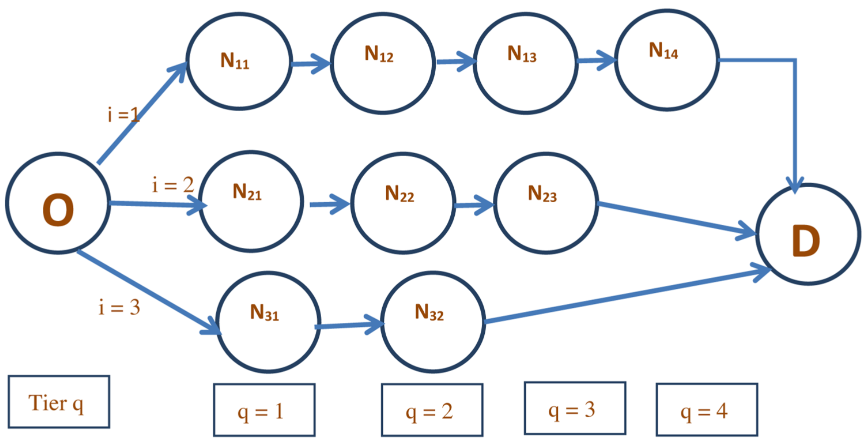


Figure 6.

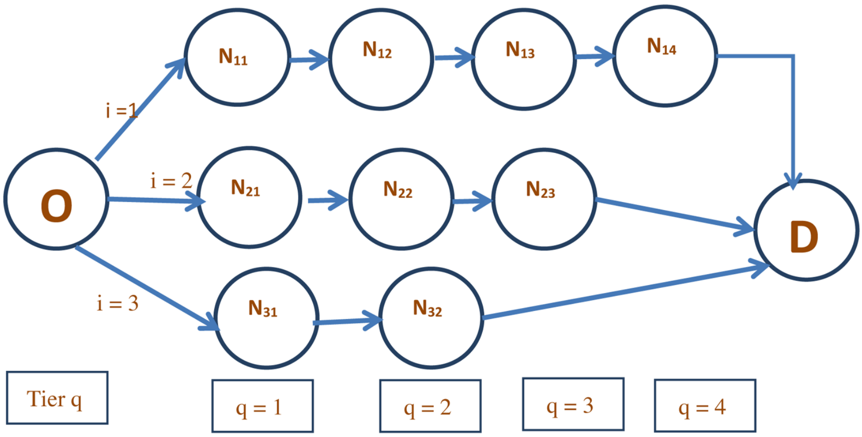


and q=1; for i = 2, j =1 and q=1; for i = 3, j =1 and q=1}; OR, it can be a desired value assigned by the shipper.

g. Procedure and Documentation complexity (PDC) for node n_{ijq}; $(\mathbf{p}_{ijq})_s$ **= $\mathbf{p}_{ijq}$/ $(\mathbf{p}_{ijq})_b$; where $(\mathbf{p}_{ijq})_s$ = standardized score of $\mathbf{p}_{ijq}$; $(\mathbf{p}_{ijq})_b$ is benchmark value of $\mathbf{p}_{ijq}$.**

The benchmark value can be the lowest $\mathbf{p}_{ij}$ in tier "q" of the multimodal network. For example: If there are 3 routes available, i.e., i = 3, the minimum

Figure 7.



PDC, $\mathbf{p_{ijq}}$, **That is,** Min{for i = 1, j =1 and q=1; for i = 2, j =1 and q=1; for i = 3, j =1 and q=1}; OR, it can be a desired value assigned by the shipper.

h. Communication system (CS-technology) availability for node n_{ij}; (Real time / on line / batch), t_{ijq} ;

$(t_{ijq})_s = \mathbf{t_{ijq}/ (t_{ijq})_b}$ **;**

where

$(\mathbf{t_{ijq}})_s$ **= standardized score of** $\mathbf{t_{ij}}$**;**
$(t_{ijq})_b$ is benchmark value of t_{ij}.

The benchmark value can be the highest $\mathbf{t_{ij}}$ in tier "q" of the multimodal network. For example: If there are 3 routes available, i.e., i = 3, the maximum CS, $\mathbf{t_{ijq}}$, **That is,** Max {for i = 1, j =1 and q = 1; for i = 2, j =1 and q = 1; for i = 3, j =1 and q = 1 }; OR, it can be a desired value assigned by the shipper.

i. Variability in terminal performance (error rates) for node n_{ijq}, $e_{ijq;}$ $\mathbf{(e_{ijq})_s = e_{ijq}/ (e_{ijq})_b}$ **; where** $\mathbf{(e_{ijq})_s}$ **= standardized score of** $\mathbf{e_{ijq}}$**;** $\mathbf{(e_{ijq})_b}$ **is benchmark value of** $\mathbf{e_{ijq}}$**.**

7. For every mode compute standardized score as sum of the following):

Figure 8.

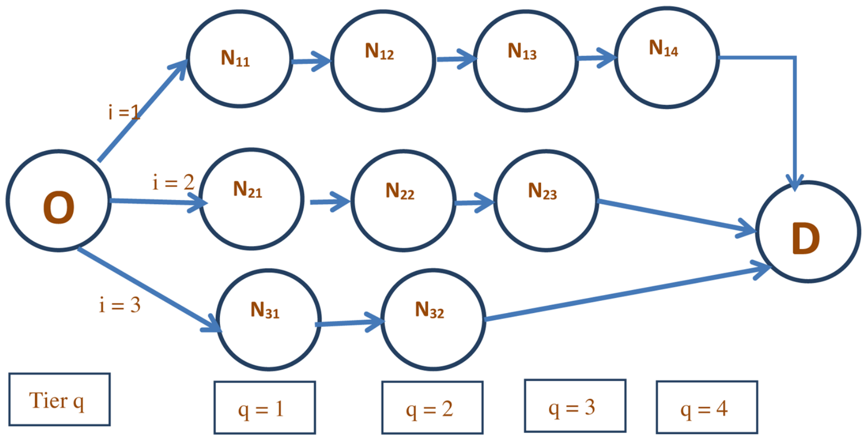
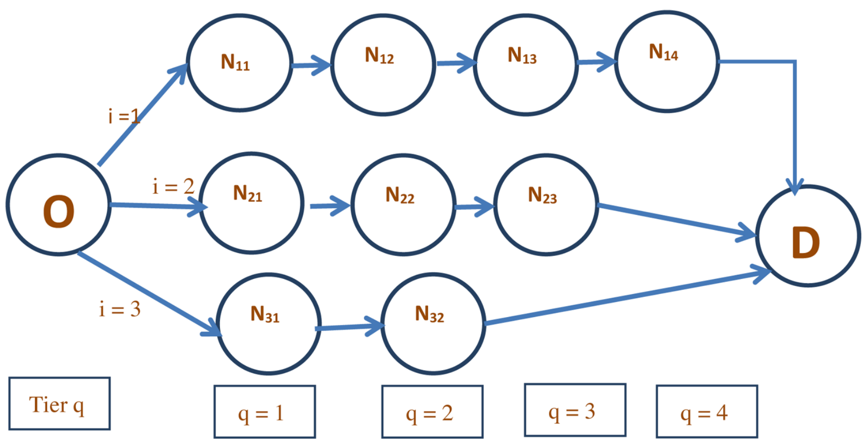


Figure 9.



Mode Score $= \sum\{[1/(\mathbf{T}_{\mathbf{ijk}})_s] + [1/(\mathbf{F}_{\mathbf{ijk}})_s] + [1/(\mathbf{D}_{\mathbf{ijk}})_s] + [1/(\mathbf{V}_{\mathbf{ijk}})_s] + [(\mathbf{C}_{\mathbf{ijk}})_s] + [1/(\mathbf{P}_{\mathbf{ijk}})_s] + [(\mathbf{S}_{\mathbf{ijk}})_s]$;

where:

$(\mathbf{T}_{\mathbf{ijk}})_s$: Standardized Score Transit Time for mode m_{ijk}, $\mathbf{T}_{\mathbf{ijk}}$
$(\mathbf{F}_{\mathbf{ijk}})_s$: Standardized Score Freight for mode m_{ijk}, $\mathbf{F}_{\mathbf{ijk}}$
$(\mathbf{D}_{\mathbf{ijk}})_s$: Standardized Score Damage rate or loss rate for mode m_{ijk}, $\mathbf{D}_{\mathbf{ijk}}$
$(\mathbf{V}_{\mathbf{ijk}})_s$: Standardized Score Time Variability for every mode, $\mathbf{V}_{\mathbf{ijk}}$

$(\mathbf{C_{ijk}})_s$: Standardized Score Customization options available for mode $m_{ijk,}$ $\mathbf{C_{ijk}}$
$(\mathbf{P_{ijk}})_s$: Standardized Score Procedure and Documentation complexity for mode $m_{ijk,}$ $\mathbf{P_{ijk}}$
$(\mathbf{S_{ijk}})_s$: Standardized Score Communication system availability for mode $m_{ijk,}$ $\mathbf{S_{ijk}}$

The route selection criteria (RSC) is set as:

$$\text{Max } (TS)_I \tag{1}$$

Subject to:

$$\mathbf{d_{ij} * (1+ e_{ijd}) + T_{ijk} * (1+ V_{ijk}) \leq C_T} \tag{2}$$

$$h_{ij} * (1+ e_{ijh}) + a_{ij} * (1+ e_{ija}) + F_{ijk} \leq C_C \tag{3}$$

where

$(TS)_I$: Total Score of Route i = $(NS + MS)_i$
$\mathbf{d_{ij}}$**:** $\sum \mathbf{d_{ijq}}$ **; Total dwell time in a route i**
$\mathbf{h_{ij}}$**:** $\sum h_{ijq}$: Total terminal handling charges (THC) in a route i
$\mathbf{e_{ijd}}$**:** Average variation in dwell time in percentage in route i
$\mathbf{e_{ijh}}$**:** Average variation in THC in percentage in route i
$\mathbf{e_{ija}}$**:** Average variation in agency cost in percentage in route i
$\mathbf{a_{ijh}}$**:** $\sum \mathbf{a_{ij}}$**:** Total agency cost in a route i
$\mathbf{T_{ijk}}$**:** $\sum \mathbf{T_{ijk}}$: Sum of transit times in route i
$\mathbf{F_{ijk}}$**:** $\sum \mathbf{F_{ijk}}$**:** Sum of freight in route i

Equation 2 refers to total time taken in the multimodal movement of cargo. That is dwell time (time at nodes), transit time and their variability. This must be less than the reponse time or customer define time - $\mathbf{C_T}$

Equation 3 refers to total direct cost incurred in the multimodal movement of cargo. That is THC, Agency Cost, Freight and their variabilities. This must be less than the permissible cost – $\mathbf{C_C}$

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Chapter 6
Management of Logistics Systems and Operations

ABSTRACT

In this chapter, the author explores and explains the different elements of logistics, namely, packaging, material handling, warehousing, and transportation. It provides the guiding principles of packaging and material handling. In this chapter, the management of warehouse has been explained. The author elaborates the concepts and different forms of shipping.

LOGISTICS ELEMENTS

Logistics Mix

Logistics comprises elements, namely, packaging, material handling, warehousing and transportation. Packaging leads to description of the cargo as bulk, break-bulk or container cargo. Bulk, dry or liquid, are handled in free form and stowed loose (i.e., without any packaging). This form cargo require distinct material handling equipment such as spade, grabs, conveyors, pay loaders, stackers and reclaimers. Bulk cargo that are affected by climatic conditions (for example, temperature, moisture and air or gases) and contaminations with external materials (such as dust or so) and organisms such as pest, insects or any micro-organisms are stored in covered warehouses such as silos or specially designed storage centres. These warehouses protect and preserve the bulk cargo. The carriers that move bulk cargo also possess

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the specifications similar to warehouses. The dry bulk carriers on road, rail and sea ensure preservation and protection of the cargo. For example, paddy or food grains are stored in silos with temperature, humidity and air regulators. Such cargo move in carriers those are cleaned and fumigated to eliminate contaminations and insects or pests respectively with water tight compartments or holds.

The cargo when packaged in bags, boxes, cartons, crates, drums and barrels or in any similar manner, ensure the first level protection and preservation followed by additional protection and preservation provided by the warehouse and the carriers. In cases where, warehouses and carriers cannot ensure such protection, the packaging is enhanced to meet all the protection and preservation requirements. For example, break-bulk packages are wrapped with water proof material such as: Craft paper coated with polyethylene to prevent from moisture, grease or bacteria; or other synthetic covers) and / or Plastic linings to protect from moisture. Goods are packaged with dry ice, or coolant gels to keep them under the right temperature. Such packaged cargo does not demand much intricacy of warehouses and carriers to protect and preserve the cargo. Break-bulk cargo are handled in pieces and hence the material handling equipment include, hand carts, forklifts, cranes and lifts. Packaging is done in the manner as specified by the customer ensuring preservation of quality. In certain cases, packaging may undergo change on the way to the destination. This is done to optimize the cost without affecting the quality of the goods. For example, goods such as food grains may be shipped from one sea port to another by dry bulk carriers to save cost. The loose cargo is then bagged in the warehouses to delivered as prescribed by the customer (i.e., in the last leg of delivery), say bagged in 50 Kg bags.

Handling of packaged material involves varied efforts, time and cost as packages may vary in dimensions, shape, volume and weight. This led to the adoption of principle of standardisation of packages and unitisation of smaller packages in to standard forms. The of boxes, cartons, crates of standard sizes and packaging them on pallets of standard dimensions are the steps in this direction. Pallets are platforms of uniform dimensions that help tying together individual packages, to give strength, protection and uniformity in efforts.

Containers, whether marine or air containers, are a step ahead of palletisation leading to unitisation and standardisation (Singh et al, 2014. Maritime or intermodal freight containers have standard dimension led down by the International Standard Organisation (ISO). The standard sizes of these boxes have led to uniformity in use of equipment. The robustness of such boxes has eliminated the requirement of covered and temperature controlled warehouses. Containers are kept in open storage yards and can move by road or rail or vessels. Cargo when packed in containers is called container cargo. Cargo that requires temperature and other climatic controls are stuffed in refrigerated containers, also termed as reefer containers. Reefer containers need power supply in yards and in carriers to maintain the desired climatic conditions. Container handling equipment includes reach stackers, straddle carriers, rubber tyred or rail-mounted gantry cranes in yards; mobile harbour cranes, ship-to-shore container gantry cranes, or on-board gantry cranes to lift on and lift off containers to and from container vessels.

Hence, it can be concluded that packaging influences other three elements of logistics, namely, material handling, warehousing and transportation.

Logistics as a System

Logistics needs to considered as a system, implying interconnectedness of logistics elements, in lieu of treating the elements as autonomous units (Neng Chiu, 1995). The system thinking, as described by Peter M Senge in 1992, refers to:

1. Treating individual entities or elements or components as part of larger system or as sub-systems inter-connected to meet the organisation goals. That is, packaging, material handling, warehousing and transportation are elements of logistics subsystem that is part of the supply chain system of a firm.
2. The effect of one element on the other need not be unidirectional and linear; there may be high-order non-linear and circular relationship. For example, timely and accurate delivery of material by a service provider may lead to increase in demand of its services; increase in demand may cause failure on the part of service provider to keep up its commitment or even refuse requests from its customer due to limitation of its capacity.
3. The structure of system gives rise to behaviour or outcome of a system. The behaviour may be changed by making parametric changes, such as change in speed of delivery or shipment size, or effect structural changes to derive the desired behaviour. The interconnectedness and processes may be re-engineered to get the desired outcome of a system. For example, if the variability of a transport carrier increases the carrier may need to be fed back with the information (on shipment consolidation time,

road congestions, speed limits and similar information) and the carrier in turn designs a different model of delivery. To elaborate this further, say a road carrier collects packaged cargo from individual senders to be delivered to a particular destination as less-than-truck load (LTL) cargo. This will cause the truck to increase its capacity utilisation, minimize cost of delivery and maximize revenue. However, in the process of consolidating cargo for shipment, the truck may delay its start of trip, resulting in variability of delivery time of goods. The transporter may instead use smaller carrier (of lesser capacity) as full-truck-load (FTL) for single sender or LTL for few consignors reducing the variability. Thus, the transporter can give assured level of service and accordingly fix its freight for the quality-of-service (QoS) provided by him.

4. Every system has a capacity that determines the maximal flow of materials (raw material, work-in-progress and finished goods). The capacity and flow can be improved by removing the constraints, upgrading technology and improving processes. However, there is a limit to growth of a system influenced by internal or external factors or both.

Every system has three components linked to one another other. These are: the input unit, process and the output. The inputs of system include resources described in terms of 4Ms – men, money, machine and material; these inputs are managed by the crucial resource "information (I)" and undergo a transformation through the processes implemented in an organisation; the resultant change is the output of a system. The performance of the system may be measured and a feedback provided to the preceding components to make corrections with respect to either inputs or processes. The logistics system, in the context level, may be illustrated as shown in figure 1. The inputs in a logistics system are similar to any other system, that is, it constitutes 4Ms and I, based on the orders received for supply or distribution of materials. The logistics process should lead to the expected output, that is, delivery to customer - On-time-in full (OTIF) in Right Condition (RC). If output does not meet the target, then either inputs or process need change.

The subsystems of the logistics system include the four elements as illustrated in figure 2.

Each of the elements, viz. packaging, material handling, warehousing and transportation act as a sub-system to the logistics system. Thus there is a packaging system, material handling system, warehousing system and transportation system.

Figure 1. Logistics system

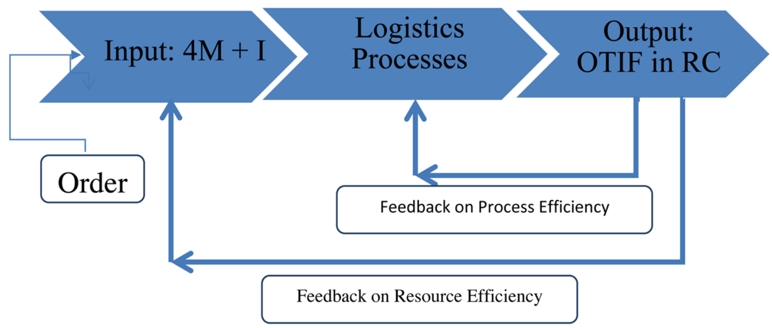
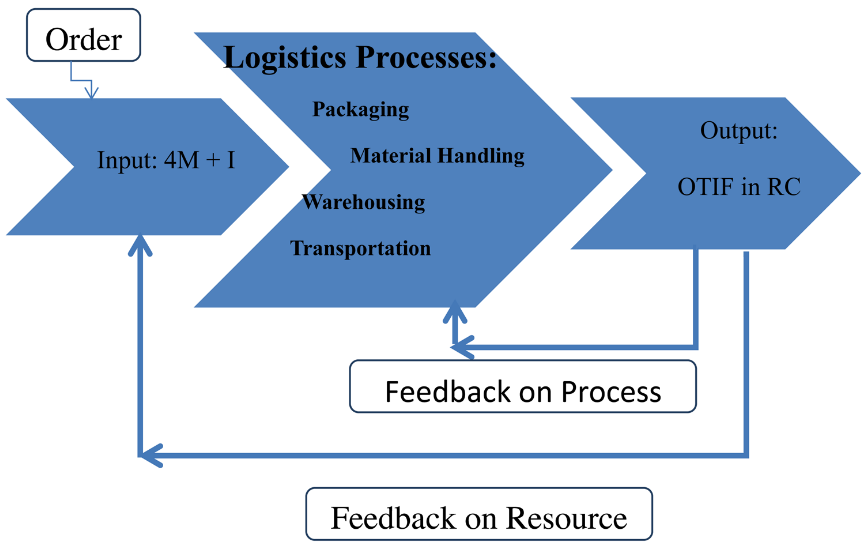


Figure 2. Logistics system: 2nd level illustration



The Packaging Sub-System

The packaging sub-system has inputs such as packaging material; packagers or packaging agency; packaging equipment such as banding and strapping machines, waterproof lining machines and similar machinery; and there is cost of packaging as well. The method and process of packaging determines the effort, time and cost of packaging. The output of packaging sub-system is said to be acceptable if materials are rightly packaged i.e., neither over packaged nor under packaged. Less packaging may cause damage while over packaging will lead to increase in cost of handling. Thus, the packaging method and process need to follow the guidelines that ensure right packaging. The dimension and weight of cargo per pack is based on customers requirement followed by quality and cost consideration. Besides, the processes need to be sustainable as packaging material and method of packaging may pose threat to environment. Packaging materials on de-stripping need immediate disposal and hence should be environment friendly. The operational issues and challenges related to packaging are detailed below.

Packaging of Cargo: Concepts

Packaging is done in different stages. Say, medicine when put in a bottle refers to the primary packaging. The bottle put in boxes imply secondary or second stage packaging. The boxes put in cartons refer to tertiary or third level packaging. A logistics manger is concerned about the tertiary level packaging. He needs to ensure that packaging meets three fold obejectives:

1. To protect the goods;
2. To keep the consignment together;
3. To prevent the goods from damaging the environment.

Packaging also aid in improving asthetic value of goods and enables tracking and tracing i.e., packages need to have a presentation value. Thus the three P's of packaging that constitutes the **packaging – mix are**:

- Protection,
- Preservation and
- Presentation.

The three levels of packaging are associated as:

1. **Primary:** Retail or customer level
2. **Secondary:** Consolidation or group level
3. **Tertiary:** Transport or movement level

In logistics we deal primarily with the third level of packaging. In case of containerisation. Containers serve as the fourth level of packaging. For example, a box containing tea is put in a carton (grouping) and cartons are unitized using pallets (transport-levels). In case of containerizations the pallets are further put inside a container.

The type of packaging depends on:

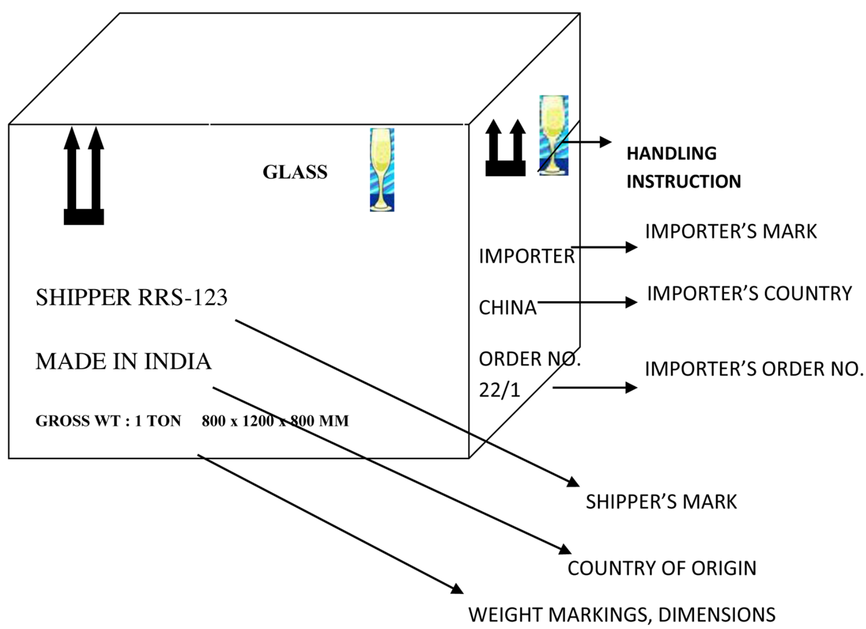
- Nature and type of goods
- Volume
- Weight
- Number of packages
- Types of packages
- Mode of transport
- Final destination

Every package need to be labelled, especially in international trade, for accounting and identification (tracking and tracing).

A label has 3 components (instructions)

1. Shipper's Information
    a. Shipper's name
    b. Consignee's name & address
    c. Cargo name
2. Shipping Information

Figure 3. Labelling in international trade



   a. Shipper's mark
   b. Consignee's mark
   c. Order number
3. Handling instructions

In case of in-land or short distance movement the goods with second level packaging may also be moved, if conditions are safe. However, whatever is the mode of packaging whether cartons or pallets or containerized, individual packages should be accompanied with labels. The symbols describing handling method needs to be included in the labels. Symbols used in international logistics are described in Table 1.

Apart from the symbols handling instructions in international languages such as English, French, Spanish, Italian or any other language may also be provided. However, such instructions are not mandatory like that of symbols. Symbols can be understood by any country while handling instructions in specific language is meant for a particular country or community. The above symbols are applicable for non-dangerous goods.

As regards goods classified as dangerous, that have chemical or physical properties which can damage other goods, or the environment or human life. Examples include explosives, flammable liquids or gases, corrosive chemicals and poisons. IMO, the International Maritime Organisation, has laid down the rules for the handling of dangerous goods at sea with regard to packaging, marking and labelling, stowage requirements, and other requirements that varies between classes of dangerous goods. There are different sets of symbols marking the goods as dangerous and exclusive guidelines regarding handling of hazardous goods http://www.imo.org/en/KnowledgeCentre/IndexofIMOResolutions/Documents/MSC%20-%20 Maritime%20Safety/328(90).pdf, accessed on 10.01.2019).

Packaging, Issues, and Guidelines

The cargo during transport is usually subjected to mechanical forces (such as shocks, vibrations, pressures) and/or climatic forces (e.g., temperature, moisture). The packaging of goods needs to be sturdy enough to withstand the rigours of stowage and multiple handling. Strong packaging is required not only to prevent the cargo from damage but also to safeguard damage of other goods in the same transport.

Table 1. Symbols used in packages

	Fragile – to handle with care		To not Tumble
	Handle With Care		Photographic material
	Keep dry		Protect from Heat
	Do not Roll		Upward Direction
	Use no Hooks		Perishable
	Keep Frozen		Clamp here
	Sling Here		Lift Cart Here
	Do not Stack		Centre of Gravity
	Do not Freeze		Live Animals

In inland and local transport, paper cartons are mostly used as the risk of damage is usually lower than in international transportation. In international transportation these packaging are supplemented with additional packaging such as pallets and/or containerization.

Bagged cargo meant for loose cargo (e.g., cement, sugar or grain) are usually put in plastic and jute bags. These are commonly used to pack traditional bulk commodities in small quantities.

Wood is still common to make cases or crates. However, cross country movement of goods wooden packaging material need ISPM 15 certification to certify that the wood used is free from pests and insects. ISPM 15 refers to international standards for phyto-sanitary measures with code 15 indicating fumigation of wood.

Liquid cargo in small quantities is package in drums and barrels made of metal or plastics, or in tank containers. Liquid cargo in bulk quantities are moved through pipelines or tanker vessels or tanker Lorries or wagons.

In global business a shipper has to comply with regulations in his as well in importers country with regard to packaging, marking and declarations of contents.

Goods should be evenly distributed and properly secured. That is, it should be well stowed within the package. Items should completely fill the case or carton to contribute to the strength of the whole package. Items which do not completely fill the package must be cushioned against shock or vibration. There must be adequate internal bracing or securing using battens (bars of wood) or dunnage (mats, wood shavings, etc.). The dunnages used should be lighter yet tough enough to protect intra-pack movements of smaller units. It should not contaminate the cargo packed

In case of the consignment consisting of a number of small packages such as cartons or crates, consolidation and unitization through pallets and/or containerization is recommended. Higher level of unitisation is recommended for ease of handling and minimizing theft and damage. Cartons on pallet are secured by strapping and banding. Additional plastic wrapping is also done to protect against water.

Unitization refers to assembly of cargo into the largest practical unit consistent with the handling, weight and dimension requirements. It has the following benefits:

- Reduces the danger of theft and damage to a minimum
- Improves accountability and productivity.

- Reduces handling stresses, as larger units require the use of mechanical handling equipment rather than crude manual techniques.

Goods moved through containers may also be palletized. Pallet packing is suitable for goods carried in containers as it eases stuffing and de-stuffing operations.

Cargo should not be “over stowed” with other packages on top of the other, in warehouses and cargo holds. Cargo which allows stacking should be appropriately packaged to withstand the weight of stacked cargo. Or else the “do not stack” symbol should be marked on the package.

In order to secure the cargo from breaking or falling apart, appropriate strapping and banding techniques should be used for all packages.

The shipper should check the regulations of the destination country as well as those of any transit countries order to ensure that they do not prohibit certain types of packing material, particularly material which is harmful to the environment.

The re-use of second-hand packaging materials (cartons or cases) should be avoided as they are more liable to breakage and /or may attract pilferage or damage..

The package should match the dimensions of the product so as to save packaging and freight costs. That is, the package should be of minimum dimension with respect to measurement of the cargo. The **space** within the package should be **optimally utilized.**

Packages should not hold items or goods attracting **different freight rates. This is so because** the carrier may charge freight based on value of cargo in a package or container. In such cases it considers the highest rated commodity to determine the freight.

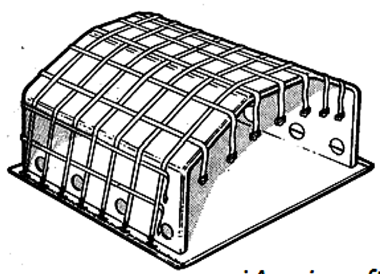
In case of items required to be stored or stowed in open area and are sensitive to moisture, goods should be provided with **waterproof** wrapping.

Over-packaging as a measure of protective packaging should be avoided. This will not only ensure optimum use of the carrying capacity but also minimize packaging, handling and freight cost.

Flexible **multi-wall bags should be used for loose or granular material**. This will provide double protection as the goods remain secure even if the outer wall ruptures during handling. The type of the bag to be chosen should suit to the chemical and physical characteristics of the goods.

An igloo is used to secure break bulk cargo different dimensions in an aircraft.

Figure 4. Igloo



Igloo as can be seen is a container of break bulk cargo of smaller dimension. It has an open front without any bottom as it is fixed on the floor of the air craft holding the cargo packages. It is a rigid shell made of fibre-glass, metal or other suitable materials. The slope of the upper portion conforms to the contours of the cargo aircraft envelope, i.e. the cross-section of the interior cabin.

Materials, such as pressed bales (canvas packages of merchandise), needs protection from moisture and water and hence an inner wrap of waterproof paper below an outer or primary cover of fiber-board material may be used., over which heavy jute or a similar material may be used as the outer covering before strapping.

In designing or choosing a suitable package, it may be useful to consult the consignee and obtain reports from his end about the packaging requirements. The consignee should provide the following information:

1. The handling gear, port equipment, and facilities available at the port of destination,
2. The inland transportation facilities available for onward movement of goods from port to the importers place.
3. The restrictions in use of packaging material.

Though packaging in logistics refers to tertiary level, consideration should be given to the "presentation" aspect of the package. That is, the design, colour and embellishment of the packages. This is expected to produce a favourable reaction in the export market and improve the competitiveness of the product.

Containers

Cargoes that move in containers are referred as containerized cargo. Packaged cargo is usually containerized. Containers are carried on dedicated container vessels called cellular container or put on trailers that moves inside roll-on-roll-off (Ro-Ro) vessels. The cellular ships have cells and it enables containers to fit into predetermined positions on board ship. This reduces complicated stowage planning as in case of break bulk cargo. Containers today carry different types of cargo ranging from liquids to large project cargo. That is, almost any commodity can be containerized. Containers have the following advantages:

1. Cargo is not manhandled while loading and unloading or at yards, instead is handled with equipment such as gantry cranes, derricks, mobile harbour cranes, rubber or rail mounted gantry cranes, etc. Reduction in manhandling causes consistent output and lowering of cost especially in developed countries.
2. The cargo put in a container needs less protective packaging.
3. Large number of individual packages having their respective cargo mark when put inside a container are identified with one shipping mark, i.e., the container number. Hence documentation and identification of cargo is simplified.
4. Tracking and tracing of containers through electronic data interchange (EDI) has increased the supply chain visibility and accounting of cargo.

The cargo can be stowed inside a container much before it arrives at port. This is done in inland container depots (ICDs) or container freight stations (CFS) away from port, near to market or production centres. This not only saves time and effort, but also reduces port congestion. The shipping companies own or lease the containers. They ensure availability of containers at the respective port of call. As such they move empty containers at their own' expense. The ISO containers are of specific sizes. That is,

1. 20' * 8' * 8.5'
2. 40' * 8' * 8.5'
3. 20' or 40' * 8' * 9.5': A 'High Cube' container

A 20 feet container is termed as a "Twenty Equivalent Unit (TEU)", and forty feet container is referred as 2 TEU or forty-equivalent-unit (FEU). However, there are a variety of heights, widths and even lengths of units in the system today. The different types including special purpose containers are given in Figures 5-14

Warehousing System

Warehousing requires storage space in all forms, namely open yards, covered storage, temperature controlled storage space and other variants depending on type of goods stored in the warehouse. It provides link for movement of road and rail carrier to bring in and take out goods. The goods are placed, lifted, shifted and rearranged using equipment such as forklifts, cranes and other types of equipment. A warehouse provides for value added services such as inventory control, stuffing and de-stuffing of goods in and out of containers, labelling and tagging, freight forwarding, inspections, light assembly and other similar jobs. The desirable output of warehouse functions include safe storage and timely delivery of undamaged goods in full (i.e., without short shipment) quantity.

Figure 5. Types of container

Type	Typical Cargo
Insulated containers	Used for frozen or cool cargo
Half height units	Steel or other heavy items
Flat racks	Timber, vehicles and odd shapes
Open top containers	Over height items
Bulk boxes	Bulk cargo such as grain or fertilisers
Open sided	Ventilated cargo such as onions
Tank containers	Liquids and chemicals in bulk

Figure 6. A typical 20' container

Figure 7. A typical 40' container

Warehouse Operations

The warehouse operations include:

1. Gate operations: Queue management, document generation and checking, entry or exit permit generation (for men, vehicle and cargo)

Figure 8. A flat rack container

Figure 9. An open top container

and its verification, scanning of packages or containers, tagging and labelling of vehicle and cargo or containers using RFID (radio frequency identification), bar coding, or other systems.

2. Cargo movement, stacking and tracking: Transferring and storing cargo as per yard plan or bay plan. Tracking of cargo using RFID or GPS (global positioning system) technology.

Figure 10. Stacking of containers

Figure 11. A refrigerated container

3. Goods repair, testing, assembly or kit preparation**:** Some warehouse provided for value added services such as repair, stitching and bagging, preliminary testing or enabling inspections, preparing kit supply by combining goods of different kinds from different consignments and putting them together in one package, or light assembly.
4. Freight forwarding: Typical jobs include contacting the carrier, booking space and arranging for cargo movement, prepare and process the

Figure 12. A tank container

Figure 13. A side and top open container

documentation and perform related activities pertaining to international shipments.

5. Warehouse and terminal management:
   a. Inventory management: Elimination of obsolescence, damage and theft
   b. Equipment management: Ensuring availability, utilization and maintenance of equipment.

Figure 14. A over dimensioned cargo (out-of-gauge) tied to a flat rack container

   c. Yard Management: Allotting space, shifting of goods from one point to another and tracking
   d. Warehouse and yard maintenance: Repairing, replacing and modernizing warehouses, yards and the system
6. Information dissemination to all the stakeholders.

Warehouse Management Systems

A warehouse needs to implement information technologies to support high quality and low cost warehouse operations, such as "Smart and Intelligent Warehousing System", "Distribution System" and similar operational management systems for effective management of its activities. This requires integration of on-line systems with various kinds of automated handling machinery and equipment systems or other real time systems.

A "Smart and Intelligent Warehousing System" will include:

- Intelligent Transport System
- Freight Forwarding System
- Container Terminal Information System /
- Intelligent Container Yard Control System
- Warehouse Management System
- Inventory Handling System
- Electronic Data Interchange

- Integrated Information System
- Warehouse Location Control System
- Dispatching Truck System
- Truck Delivery Management System
- Container Tracking System

Intelligent Transport System

This system supports advanced data search function, contributing to swift and accurate operations (import, export and cross transportation) and up-to-date information supplies to customers.

Freight Forwarding System

This system provides detailed information on import from origin to final destination. With this system, the firm can share the information linking key sections (service, customs clearance, warehousing, distribution), and it helps increasing efficiency and overall cost savings.

Container Terminal Information System / Intelligent Container Yard Control System

This is a management system for container terminal operations. The Intelligent-Container-Yard-Control System controls various information on receipt, discharge, internal shifting, stuffing and de-stuffing; and Customs clearance.

Warehouse Management System

This system is designed to control inventories. It allows the precise control according to characteristics and state of each product. This system ensures order fulfilment and minimizes obsolescence. It is linked with other systems such as Inventory Handling and Warehouse Location Control System.

Inventory Handling System

This system controls operations relating to delivery of materials stored in the warehouse. It enables tracking of packages, its shelf life (to avoid obsolescence), issuing invoices and labels, order management (pick up schedule, quantity and despatch planning), and also provides variety of customized information.

Electronic Data Interchange (EDI): With Customers

This system is used to interchange data on receipt and shipment of goods, inventories and other relevant information with customers in EDI format. EDI aims interchange of data or documents as per structured format agreed upon by the terminals and their stakeholders. These formats are either adopted from global standards such as UNEDIFACT (United Nations Electronic Data Interchange for Administration, Commerce and Transportation; or as per mutually agreed format between business partners. In India all major ports and their stakeholders namely, shipping agents, freight forwarders, transporters, Container Corporation of India (CONCOR), container-freight-stations (CFS), inland-container-depots (ICD), banks, and others have come together and implemented an EDI system called 'Port Community System (PCS) for electronic interchange of documents. At present use of block-chain technology makes electronic exchange of information more secured.

Integrated Information System

This system aims at providing web-based integrated information on inventory, state of goods and all other details of goods stored in a warehouse. This system will enable downloading of data is in various format such as pdf, csv, xml and other similar formats, which enables customers to create their reports or load in to their databases. This system can be customized to send alert e-mail and SMS messages automatically to the concerned according to the set rules, such as the departure schedules of trucks and carriers, upper or lower limits of inventories or the expiration dates etc. to keep timely and appropriate inventory management.

Warehouse Location Control System

This system enables tracking and tracing of inventory in a warehouse.

Dispatching Truck System

This system ensures efficient movement of goods in and out of a warehouse. It manages to and fro truck and rail movement based on various rules and constraints, such as time restrictions for truck movements within a city, holidays, just in time specifications and other delivery requirements. This system aids in simplifying dispatch planning and realizing the best truck routing and scheduling.

Truck Delivery Management System

This enables tracking of vehicles in real time (can be tracked on the map on the website), primarily, using Global Positioning System (GPS). It also guides vehicle routing and diversions.

Container Tracking System

This system enables tracking of containers and hence efficient delivery arrangement. It provides container delivery status, such as, container pickup, load on board chassis, status of delivery and empty container return, and similar information. It primarily uses radio Frequency Identification (RFID) or global-positioning-system (GPS) technology for real time information.

Material Handling

Primary Components of Material Handling (material handling mix) include:

Material: Bulk – dry or liquid; break bulk – standard or over-dimensioned cargo (ODC); and containers

Moves: Nature of material movement in warehouses, yards and berths or platforms

Method: The methods include manual, semi-automated and automated handling of goods. Automation includes use of auto-guided-vehicles (AGV), conveyors, robots and drones in handling of material. Semi-automated handling methods include use of cranes and equipment driven under human intervention. Methods also imply directly delivery of materials from one point of storage to another or loading on the carriers; or may involve combined moves of material where use of more than single equipment is involved. For example, a reach stacker may take container from a yard and put it on a trailer to be moved to a berth from where a quay crane loads it on board a ship. Materials, moves, and methods constitute the material handling mix.

The 5 key inputs for planning of material handling are:

- Product (what)
- Quantity (how much)
- Routing (where)
- Support (with what back up)
- Time

The physical characteristics that affect movement of materials include:

- Size
- Weight / Density
- Shape
- Risk of Damage
- Condition

Principles of Material Handling

There are 13 principles to follow in material handling. These are:

1. Planning Principle: it states that, planning should preceed any activity such as material handling. It basically aims at answering 5 Ws and 1 H. That is,
    a. Where are we: The present inventory of material handling activties, performance, resources, processess and skill
    b. What do we want (where do we want to go): The plans ahead with regard to change or addition in activities, enhancement of performance, optimization of utlilisation of resources, efficacy of processess and skills.
    c. Why (purpose): The customers' requirement in terms of time and place utility; regulations, cost control and competetitiveness are motivation behind any planning process with regard to material handling.
    d. When (time frame): The time line for installing new equipment, modernising the old ones, re-engineering the processess, upgarde the skills are required to be firmed up.

e. Who (responsibility): The responsibility matrix indicating the different levels of responsibility assigned to different professionals to execute the plan is prepared.

f. How (procedure): The method and approach is essential for successful implementation of the plan. Besides, tactical planning for scheduled and predictive maintenance, procurement of spares and operations are done. Day-to-day planning involves allocation of resources – men and equipment to different job areas, accounting of moves, inventory and receipt and despacth status.

2. System Principle: it states that a systematic approach to material handling leads to integration of all activities in supply chain. The sub-systems such as receiving, storing, shipping and transportation must be coordinated with supply chain activities such as assembly, production, packaging and distribution.
3. Material flow principle: An organized flow of material reduces back tracking, deviations and stoppages minimizing delay, cost and damages.
4. Simplification Principle: Simplification of procedures and proceses leads to effective material handling (i.e. it results in less error and maximum customer satisfaction)
5. Space Utilization Principle: Flow of material should not be inhibited with unorganized storage of material. The stowage should be done in a way such that it optimizes utilization of space.
6. Unit Size Principle: Unitization leads to effective material handling. It reduces material handling moves, enhances the cycle time and enables better control on the activity. Use of pallets, containers are examples of unitization
7. Mechanisation Principle: Material handling should be automated to the extent possible as it improves consistency and reliability, thus reducing error, uncertainty, time and cost.
8. Gravity Principle: Use of gravity enables conservation of energy and minimization of cost. Hence where ever feasible use of gravity should be made. Movement of slurry through conduits is an example of use of gravity inmaterial handling.
9. Equipment Selection Principle: Equipment differ in terms of type, size, weight of material it can move and its cycle time. Thus selecting the right equipment for a right job is an important factor. For example, use of slings, in lieu of spreaders, are not preferred for lifting of containers.
10. Standardisation Principle: Standardization of equipment models, procedures, process and flows of materials (incluing its packaging)

enhances productivity maximizing storage capacity of terminals and warehouses. It also aids in pooling spares across fleet of equipment and also optimizes deployment of other resources.

11. Utilisation Principle: Selection of equipment and method of handling should be such that the utilisation of equipment and all other resources are optimized. For example, a 20 ton crane if used to lift 8 ton packages is an example of under utilization.
12. Dead Weight Principle: Material handling should aim at reducing idle and empty movement of equipment.
13. Safety Principles: Material handling should follow principles of safety to reduce loss of life and damage to goods.

Apart from the major principles stated above, other principles include maintenance, control, capacity, adaptability, performance and obsolescence principles. These principles focus on availability, utilization and sustainability of material handling operations.

Selection of Equipment

The selection of equipment is based on material, methods and moves; and on factors such as lifting or carrying capacity, maneuvrability, turning radius, stacking hieght, cycle time, economic life and cost.

Example 1: Container Handling Equipment in Warehouse and Yards

Fork Lift Trucks

A fork lift truck is a low capacity (generally 2-10T) and low hauler (50-100mts) of goods. It is used to move and lift goods inside a warehouse or stuff a container or make small moves of cargo in the terminals. The maximum capacity of forklift can go upto 50Tons. It has normal lifting capacity between 10 to 15 feet, while it can go upto 36 feet or so.

It is used for moving containers in a container yard. It moves on rail tracks and hence its maneuverability is reduced. Similar to RMG are the Rubber Tyred Gantry Crane (RTG) performing similar functions. RTG also move on a definite path. The spreader is used to lift containers.

Figure 15. Fork lift truck

Figure 16. A rail-mounted-gantry crane (RMG)

Reach Stackers can move containers in a yard with greater maneuverability. Unlike RMG or RTG it can move from one yard to another

Straddle Carrier (SC)

These are used for container movements within yards and also between container yard and the berth.

Figure 17. Reach stacker (RST)

Figure 18. Straddle carriers

Table 2 below gives a comparative study of different types of container handling equipment at yards.

Example 2

Container and Cargo Handling at Berths

The different types of equipment used for cargo operation at berths include:

Figure 19. Straddle carrier (SC) stacking containers

Table 2. Parameters of comparisons

Parameters	SC	RTG	RMG	RST
Stacking Height	2- 4 High	4 – 6 High	4 – 6 High	3- 4 High
Moves per hour	20 – 30	Loading and unloading of railcars: 30 moves per hour - Stack work: 20 moves per hour - Loading and unloading of road trucks: 15 moves per hour	20 - 45	Loading and unloading of railcars: 20 – 30 moves per hour depending on travel distances - Stack work: 15 moves per hour - Loading and unloading of road trucks: 10 moves per hour
Storage capacity	750 TEU per hectare on 4-high stacking	Approximately 1000 TEU per hectare, based on 4-high stacking.	1000 TEU per hectare on 4-high stacking	Approximately 500 TEU per hectare, based on 3-high stacking
Economic Life	10	15	20	20
Cost	Medium	High	Highest	Low

1. Mobile Harbour crane: for containers, with around 20 to 25 moves per hour
2. Ship- to - Shore Gantry Crane: for containers and break-bulk cargo, with around 10-12 moves of container per hour.

Table 3. Equipment type and stacking area

Sl. No.	Handling Equipment and Method	Stacking Height of Container	A_{TEU} in m²/TEU With the Following Breadth or Line of Containers				
			1	2	5	7	9
1	Chassis	1	65				
2	FLT (Fork Lift Truck)/ RS (Reach stacker)	1	72	72			
		2		36			
		3		24			
		4		18			
3	SC (Straddle carrier)	1 over 1	30				
		1 over 2	16				
		1 over 3	12				
4	RTG (Rubber tyre gantry) / RMG (Rail mounted gantry)	1 over 2			21	18	15
		1 over 3			14	12	10
		1 over 4			11	09	08
		1 over 5			08	07	06

3. Ship's Derrick: for containers and break bulk cargo, with around 8-10 moves of container per hour
4. Ship's Grab or shore based Grab Cranes for loading/unloading of dry-bulk cargo. The capacity of such grabs are generally 12-13 cbm (cubic metre) per grab. In Indiian scenario around 10000-15000MT of bulk cargo is handled per day per ship. In highly mechanized environment the cargo handling could be to the tune of 40-50 thousand MT per day per ship.
5. Pumps and pipelines: These are used for fluid cargo. The loading/ unloading capacity depends on the capacity of the pumps and diameter of the pipes.

Transportation: Characteristics and Comparison of Modes of Transportation

Role of transportation in logistics: Transportation cost absorbs between ten to fifty percent of total logistics costs. An effective and inexpensive transportation system contributes to the following:

1. Greater competition in marketplace: *Transportation make goods available at the right time and place leading to market penetration*
2. Greater economies of scale in production: *Wider markets can result in lower production cost. It also permits decoupling of market and production sites.*
3. Reduced prices for goods: *Inexpensive transportation contributes to reduced prices.*

The demand for the commodity is not the same as demand for transport. Commodity can move in any feasible mode of transport. The choice of transport would depend on type of cargo, time, cost and host of other factors. The transportation cost per unit distance within the country always account for the final node of volume of trade than the same exportable items of other countries.

Service Choices: There are five basic modes of transportation, namely, water, air, rail, road, and pipeline. These modes differ in terms of price, average transit time, time variability, Price, loss and damage. The cost of transportation or freight varies in terms of mode of transportation, commodity being shipped, distance and direction of movement, any special handling required, cargo volume, demand and supply of carriers.

Less-than-truck load (LTL) or movement of cargo by liner shipping lines will cost more compared to Full-truck load (FTL) or shipment by chartered vessel (tramp shipping). The charges are therefore categorized as liner rates (or line haul rates) and charter rates. In liners shippers pay in terms of volume or weight of cargo, where as in chartering shippers pay in terms of voyage (or trip) or time period for which the carrier is chartered.

Cost of service varies from one mode of transport service to another. The hierarchy of cost for different transport services is as follows:

Air > truck > rail >water > pipeline

A study shows that in international trade the cost of transportation by road is 3 to 7 US Dollars per ton per KM compared to 2 to 6 US Dollars per ton per KM by rail. Cost of transportation by air would be in terms of kilograms i.e. around 400 to 500 USD per 100 kg or 30 to 50 USD per Kg. The cost by water transportation is the lower compared to transportation by rail. The cost of transportation by pipeline is the least. Any one or combination of the different modes of transportation can be used for movement of goods from one place to another. Selection of modes of transportation is made based on best balance between time, quality of service and cost.

Transit time and variability affects the choice of mode of transportations and carriers. Transit time variability can be used to measure service providers' efficacy in door-to-door movement of cargo. It helps in comparing carrier performance. Variability refers to the usual differences between the desired and actual time taken. Variability may be due to change in mode of transportation and reasons such as effects of weather, traffic, congestion, and number of stop-offs and differences in time to consolidate shipments. The variability of different modes of transport is as follows:

- Rail has the highest delivery time variability
- Air has the lowest delivery time variability

Performance modes of transportation vary with respect to the distance. For example:

Distance greater than 600 miles:

- Air freight is the fastest mode followed by truck load, then less truck load and then comes rail.

Distance less than 600 miles:

- Air and truck are comparable

Distance less than 50 miles:

- `Transit time is influenced by pickup and delivery operation than line haul transit time.

Delivery time variability and Loss and damage becomes factor for selection of a carrier.

- **Rail:** A rail carrier is basically a long hauler, slow mover of materials. It is primarily suited for low valued bulk commodities. However it is widely preferred for manufactured products like automobiles and project cargo. Rail movement is usually referred as rake-movement. A rake consists of number of wagons. A wagon typically can hold 50 ton to 60 ton. A typical full rake consists of 40 to 60 different types of wagons (BCN, BOXN, flat wagons and similar). BCN are covered bogie wagons and can also be used for goods requiring protection from sun and rain. BOXN wagons are typically high-sided-bogie-open top wagons. Carload (or rake-load) quantities refer to predetermined shipment size usually approaching or exceeding average capacity of a rail car, i.e., say 2000 to 2500 tons. Services of rail also include - various stop off privileges which permit partial loading and unloading, pick-up and delivery, diversion and re-consignment. These allows flexibility in routing and changes in the final destination of a shipment while en-route. In rail transport, fixed Cost is high while variable cost is low. Variable cost includes loading, unloading, billing, collecting, yard switching and multiple shipment costs. The cost per unit is lower for increased shipment volume.

- **Truck:** This is **b**est suited for semi-finished and finished goods with an average length of freight haul of 646 miles for truck load and 274 miles for less truck load. The shipment size is smaller than rail. It is advantageous for door-to-door service (less material handling, better availability and frequency of service). Trucking has a service advantage in the small shipment market.
- **Air:** The appeal of air transportation is its unmatched origin–destination speed, especially over long distances (maximum delay in surface freight handling and movement in door-to-door delivery time). Delivery time variability is low in absolute magnitude, even though air service is quite sensitive to mechanical breakdown, weather conditions and traffic congestions. Compared to water, average delivery time variability, in terms of percentage, is high as a result one can rank air as one of the least reliable modes. However, loss and damages are less.
- **Water:** This is the **s**lowest mode of transportation; can handle liquid and bulk cargoes as also high valued cargo in containers. The loss and damage in general low as it is not of much concern with low valued bulk products and loss due to delays are not serious (large inventories of low valued items are often maintained). But for valued good substantial packing is needed to protect from rough handling of goods. Waterways are better means of transport of goods across the border; suited for goods transported in large quantities, goods that can be containerized, cargo capable of withstanding longer lead times in supply and cargo that requires less careful handling. Now-a-days almost all types of cargo including cars and vehicles (roll-on - roll-off ships as well as conventional carriers), finished goods, raw materials, small sized or large shaped cargo are transported through waterways.

- **Pipeline:** Pipelines **o**ffers limited range of services and capabilities. It is used for movement of fluids. It is slow but tempered by the fact that products move 24 hours a day and 7 days a week. It is the most dependable mode of transport; the loss and damage is low. Pipeline parallels the railroad in cost characteristics. The fixed cost is high and the variable cost (consumption of power and cost of operation) vary greatly with line throughput and diameter of pipe. The cost per ton mile is low compared to all other modes of transportation.

THE TRANSPORTATION CHOICE FRAMEWORK

Volume: Distance Trade-Off

Every mode of shipment has restriction in terms of volume or weight of cargo it can carry. Air freight carriers can travel longer distance to the extent of 5000 km while, generally, have cargo carrying capacity of 50 to 60 tons; and some air crafts can carry up to 250 tons. Sea going vessels can also traverse longer distance and have carrying capacity in thousand tonnes; the largest sea going vessel such as ultra-large-crude-carrier can carry up to five hundred thousand tonnes.

Rail carriers are long haulers, optimally up to 2000 Km with carrying capacity of 2000 to 5000 tons per rake. Road carriers generally have 20 to 40 ton capacity, and certain multi-axle carriers can take up to 200 tons per carrier. Road carriers are best suited to move cargo within 1000 Km.

Time: Cost Trade-Off

It can be observed that cost increases with reduction in transit time. So we need to trade-off between cost and time. Road and air are faster mode of transport but are costlier than rail and sea transportation. In inland transportation, a choice between road and rail is required to be made while movement across borders, a similar comparison is required to be made between air and sea.

Speed: Volume Trade-Off

It is evident that high-volume cargo-carriers move at less speed than low volume cargo movers. The speed of air craft ranges between 500 to 900 miles per hour; while ships move at a speed of 10 to 20 Knots per hour. Road carriers are faster than rail not in terms of its speed but because of its door-to-door delivery capability.

Choice of Transportation Based on Opportunity Cost

The choice between air and sea transporation is primarily made on the criteria of cost and time. Air transportation is known for movement of goods which are perishable, or have urgency or have high value – volume ratio. However, air transport can also be used for categories of cargo as it reduces opportunity cost and increase profitability on following account:

Air transportation speeds up delivery on products or services, this leads to following advantages:

1. Firms can seek wider markets from a fixed facility. Centralization of facility reduces redundancy and reduces cost; and also enables better manageability.
2. Wider market resulting in increased sales will enable achievement of economy-of-scale thus reducing cost of production. This in turn will increase profitability.
3. Firms that have launched a new product or have ventured in a new market cannot afford to have higher inventory levels. Air transportation with faster delivery ability can help reduction in inventory levels.
4. Faster delivery result in lower inventory levels. Thus cutting down the inventory and storage cost while improving the service
5. Air cargo incurs lower Insurance cost.
6. Air cargoes are handled in much sophisticated environment. Superior handling means lower risk of damages and less insurance cost. The packaging requirement is also less for air cargo, thus reducing packaging cost and terminal handling charges.
7. Faster delivery enables faster payment collection. Thus by shrinking the transit time of expensive products, air cargo helps its manufacturers get payments faster.
8. Air cargo has lesser variability in transit time compared to ocean liners and hence there is increased dependability and higher customer satisfaction.
9. Faster delivery of materials such as spares causes reduction in breakdown time; and hence results in minimization of production losses and customer dissatisfaction.

Multimodal Transportation: The distance-speed-volume – time and cost optimization can be achieved by combining different modes of transportation i.e., through multi-modal transportation.

Quality of Multimodal Logistics Chain

A multimodal logistics chain comprises different nodes connected with modes of transport for movement of goods from origin to destination. The logistics decision is based on selection of nodes and modes of transport based on the different dimensions described in chapter 5. The objective of such a combination is to minimize cost, ensure delivery on time – in full, in right condition and maximize quality of logistics. All factors excepting quality are quantitative and directly measurable, while quality is a qualitative and is an indirect measure. The quality of any service such as logistics is the gap between the perception of the stakeholder and actual service received.

The dimensions of quality of multimodal logistics comprise variations in 5Rs (right time, place, form, price and practices); complexity in procedures and documentation; extent of collaboration amongst stakeholders; and efficacy of communication system in the logistics chain. Non-conformance to quality results in opportunity cost and hence needs to be accounted when selecting the logistics chain (Dua & Sinha, 2018a; Dua & Sinha, 2018b, Dua & Sinha, 2018c) .

Dynamics of Shipping

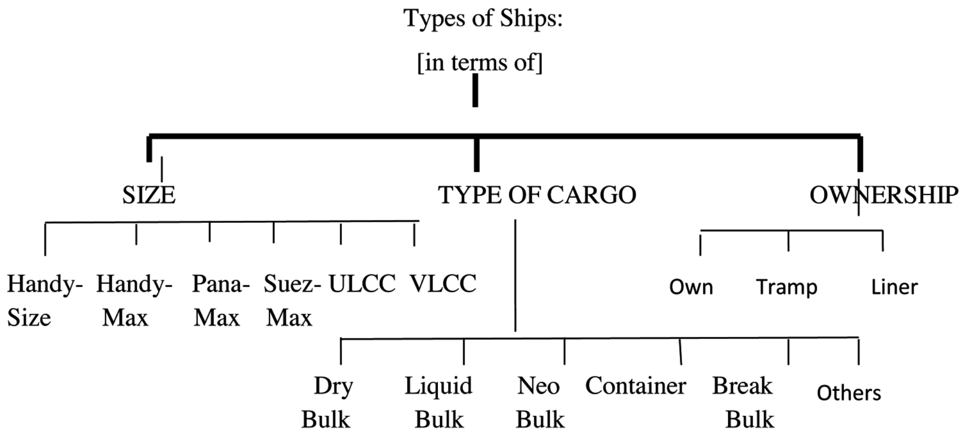
Ocean Ships and Shipping

Waterways is an important mode of transportation as it carries more than 75% by volume of the global trade; and 50% or so by value of the total goods traded. Shipping can be categorized from different perspectives such as ownership, type of cargo, size, routes ships takes, freight and flag of registration. Figure 20 depicts the primary categorization.

Ownership

Shipping can be categorized in terms of ownership of vessels and the purpose it serves.

Figure 20. Categorization of shipping



Private fleets: A firm may own ships for transfer of its own cargo (raw material or intermediate products or finished goods). Firms maintain private fleet especially for movement of bulk cargo such as oil or other liquid cargo; dry cargo such as coal, cement, iron ore etc., or neo- bulk cargo (such as lumber or automobiles). Firms integrate vertically to own ships and have control on shipping i.e., availability (of right kind of ship to meet their special needs) and the cost of shipping. The size and type of vessel depends on the company's need. Private fleet is feasible when there is *frequent* requirement for movement of *full ship load* cargo; yielding an acceptable return-on-investment (ROI).

Tramp shipping: In cases where there is *intermittent* requirement for movement of *full ship load* cargo, companies opt for hire (chartering) of ships. Chartering is termed as *tramp shipping*.

Liner shipping: If the cargo volume is not full ship load, a shipper needs to book space in liner vessels that carry goods for many shippers. This is termed as *liner shipping.*

Shipping in Terms of Cargo Types

Shipping can be described in terms of type of cargo it moves, such as container shipping for containers, general cargo shipping for break bulk and container cargo, dry-bulk (tramp) shipping for dry-bulk cargo and tanker shipping for liquid cargo.

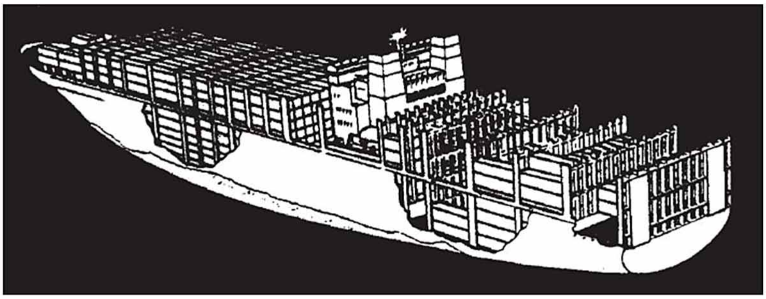
Bulk (dry or liquid) shipping: Bulk cargo exists in free form and is stowed loose in the vessel. The dry bulk cargo needs to be uniformly spread out in the ships hold to maintain stability. Pay-loaders are lowered inside the ships' hold to uniformly stow the cargo. Liquid cargo vaporizes during the voyage and hence appropriate gap is maintained and safety valves are used to release the vaporised liquid, reducing the pressure inside the hold. Dry bulk cargo such as rice may also be packaged as bagged rice and shipped along with bulk rice. This is done by placing the bagged cargo on top of bulk rice to give the load stability. Bulk cargo moves by weight. The weight of cargo loaded in a ship is determined by measuring the change in the water level of the vessel before and after loading. This change in water level indicates volume of water displaced. The volume of this displaced water is equivalent to the volume of the cargo loaded. Volume multiplied by the density of the cargo gives weight. However in case of cargo such as coal the cargo may have absorbed water due to rain during the voyage. This would increase the coal's moisture content but adds nothing to its usefulness to the ultimate customer. The shipper pays freight and terminal handling charges for the increased weight put gets paid for the useful content of the cargo. Hence, prior to loading and unloading sample of coal is analysed to record the energy content, measured in GCV (Gross calorific value). At the unloading port the purchaser pays for the gross calorific value of the cargo. Hence, for bulk carrier two additional agencies, namely, quality surveyor and draught surveyor play a crucial role. Quality surveyor collects sample of material at the time of loading and un-loading while draft or draught surveyors measures change in water level to assess the weight of cargo loaded and unloaded. Bulk carriers have larger capacity than container carriers.

Break-bulk or General Cargo Shipping: Break-bulk is also referred as general, or packaged, cargo. It has high value per unit of weight, as it is semi-finished or finished goods. It moves by number or count. They usually move in liner vessels. This cargo is loaded and unloaded on a piece-by-piece basis. General cargo vessels are smaller in size compared to container vessels and bulk carriers.

Container shipping: A fully container carrying ship is called a cellular ship. Sometimes containers are also moved along with other type of cargo. As they are stowed on the weather deck while the major cargo is stowed in the ship's hold.

Neo-bulk Cargo Shipping: Break bulk cargo of a particular type when moved as full ship load is termed as neo-bulk cargo. That is, it has some characteristics of bulk and some characteristics of break-bulk cargo. For example, logs, automobiles and steel. A particular type of cargo move by specialized ocean vessels such as vehicle carriers, log carriers or steel

Figure 21. A hatch-less containership, consisting of high racks placed inside a hull



carriers. These vessels are in no way similar and cannot be interchanged. Vehicle carriers are generally multi-racked, provided with ramps for vehicles to roll on to the ship and roll down to the berth; require less water depth as the density of the goods is less whereas log carriers carry logs in their open holds and require greater draft as the goods are dense. The logs are difficult to handle at all points, i.e., at yard, berth and on board the ship resulting in longer turn-around-time (TRT) of ships. These ships are smaller in size than the container vessels because of the difficulty in handling of goods. Stacking of logs in yards is not only time consuming but also accident prone as these are heavy cargo. Whereas parking of cars are much easier, but are not stacked and hence require large acreages of land. Compared to bulk cargo it is usually worth more on a per-kilo basis. The movements of neo-bulk cargo often are a little off the routes of major shipping lanes.

Figure 22 shows the front of a cross-section of an auto carrying ship. It carries vehicles of different dimensions.

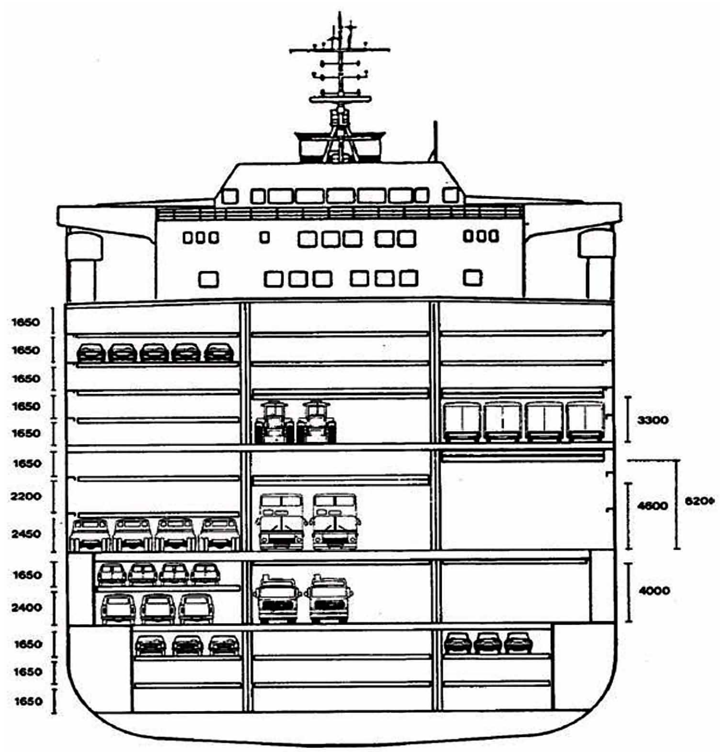
Automobiles and logs also move as containerized cargo. There are special auto-rack containers that can be customized into different shapes to accommodate batches of autos with varying dimensions.

Mixed Cargo Carriers or Combi-Vessels: Some vessels carry more than one type of cargo. The most common are the specialized carriers carrying cargo in their holds while stowing cargo of different type on their deck. These are termed as “deck” cargo. This practice is normally termed as “topping off”.

It is difficult to construct categories into which one can carefully classify all cargoes. For example there are ships which carry loose grains in its hold and containers in its weather deck.

Deck cargoes are such that it does not require protection from weather conditions, for example container or project machinery.

Figure 22. An auto-carrier



Project Cargo Carriers: Project cargo is break-bulk or general cargo usually having higher weight and density; and sometimes is over-dimensioned. These are not of common type as it is mostly fabricated for a single and certain purpose. When project cargo is oversized it requires special transportation equipment and handling in both land and sea.

Other Varieties of Ships Include

1. OBO (Oil – Bulk - Ores) carriers: It can carry bulk cargo in both dry and liquid form.
2. Ro-Ro: (roll-on-roll-off) carriers carry cars or vehicle, containers or machinery lashed on trailers.
3. Refrigerated vessels: it carries goods that require temperature controlled storage during movement e.g. fresh foods, plant and animal products. These are special type of break-bulk vessel.

Characteristics of a vessel: A vessel has the capacity to hold cargo, bunker (fuel oil), storage materials for vessel use, engine and other machinery and men. The total carrying capacity of a ship is termed as its "dead-weight tonnage (DWT)". The cargo carrying space is designed differently depending on the type of cargo. Conventionally, a ship's carrying space in the hull is compartmentalized into holds. One or more hold makes a hatch. These hatches are covered with hatch covers. However, in case of fully containerized vessels, there are no hatches, but are provided with guide rails to hold the containers in its hold as well as on the deck. Oil carrying vessels called oil tankers do not carry deck cargo. Cargo on board the ship may be handled with ship's own crane and derrick or with equipment on shore (at berth). Liquid cargo is handled with pump and pipelines. Large ships are normally gearless (i.e. with no cargo handling equipment on board the ship). Gross tonnage (GRT or gross registered tonnage) is defined as the number of units of 100 cubic feet of permanently enclosed space in the ship, leaving out "exempted spaces" like double-bottom and peak tanks. Net tonnage (NRT or net registered tonnage) is gross tonnage less spaces that does not earn revenue, such as the engine room. Gross tonnage is often used to compare the relative sizes of various nations' fleets.

Category of Ships in Terms of Size

Ships vary in terms of size and hence the routes act as a constraint in navigability of ships. Table 5 describes the sizes and the shipping routes pertaining to different sizes. Size is described in terms of DWT, length-over-all (LOA), width (beam), draft requirement below water and above water (air draft).

Shipping Stakeholders: Major Players in Shipping Include

The of role of different stake holders in the global logistics are given in table 6.

Freight Forwarders vs. NVOCC

The NVOCC can and sometimes do own and operate their own or leased containers whereas a freight forwarder does not. In certain countries like USA, the NVOCC operators are required to file their tariffs with the government regulatory bodies and create a public tariff. NVOCC is in certain areas accorded the status of a virtual "carrier" and in certain cases accepts all

Table 4. Size of vessels and shipping routes

Sr. No	Type of Vessel	Description	DWT	LOA	BEAM	DRAFT	AIR DRAFT	CARGO
1	Cape Size	Travels between oceans, i.e., through capes such as Cape of Good Hope or Cape Horn. Too big to pass Suez Canal	150000+	1115 ft +	184ft +	72+ ft	No restriction	Mainly bulk
2	Suez Max	Can pass through Suez Canal	70000-150000	899 ft (272m)	151 ft (46 m)	72.2 ft (22m)	223.1 ft	All types
3	Panamax	Can pass through Panama Canal Neo-panamax vessel	60000-80000: 5000TEU Ships with 13000 TEU can pass through newly built lock gates	761 ft (294.13m) 1,400 ft (426.72 m)	105 ft (32.31 ft) 180 ft (54.86 m)	39.5 ft (12.04 m) 60 ft (18.29 m)	190 ft (57.91 m)	All types
4	Handymax	Smaller vessels sailing, mainly, to and from feeder ports	<50000	<650 ft (189.9 m)	<106 ft (32.26m)	39 ft (12m)	-	All types
5	Handysize	-do-	<30000	558 ft (170m)	<89 ft (27m)	< 32 ft (9.8m)	-	Mainly break bulk
6	Aframax	Crude tankers those agreeing to follow a AFRA (average freight) rate. These vessels are midsized operating in OPEC countries.	80,00 to 1,20,000	780 ft	125 ft	> 18m	-	Liquid bulk
1.	Malaccamax	Ship capable of passing through Malacca strait	< 300000	<1115 ft	<184 ft	82 ft (25m)	-	All types
2.	Seawaymax	The vessels that can fit through the canal locks of the St Lawrence Seaway	< 28000	740 ft (226m)	78 ft (24m)	26 ft	-	All types

Table 5. Role of different stake holders

Sl. No.	Stake Holder	Function
1.	Exporter / Importer	Supplier and receiver of goods respectively.
2.	Inspection Agency	Certifies of goods quality as per contract
3.	Packaging Agency	Packaging of goods
4.	Frieght Forwarder	Books space in the ship, liason with Port authority. Some provide additional services such as warehousing, material handling and transportation.
5.	Transporter	Provides transportation of goods
6.	ICD / CFS Operator	Provides for stuffing and de-stuffing containers, Customs examination and approval; and onward movement from ICD / CFS to port and vice-versa. Serves as a "Dry Port".
7.	Customs House Agent	Does documents – clearance from Customs.
8.	Customs	Permits import or export of goods from exporting country. Collects import and export duty wherever applicable.
9.	Shipping Agent	Liasons on behalf of ship owner and shipping companies.
10.	Port	Providers loading, un-loading and associated facilities to the ship, provides storage space, inspection facilities by Customs for cargo and other value added services.
11.	Ship's Master	Endorses receipt of good on board the ship; does stowage planning and manages ship operation.
12.	Stevedores	Provides cargo handling services on board the ship
13.	Draught Surveyors	Determines weight of goods
14.	Quality Surveyors	Determines quality of goods at the time of loading and un-loading to and from vessels.
15.	NVOCC	A shipment consolidator or freight forwarder who does not own any vessel, but functions as a carrier by issuing its own bills of lading or air waybills, assuming responsibility for the shipments.
16.	Banks	Effects transfer of funds, provides loans – packing credit, foreign currency, stands as guarantee /negotiates documents, hedges currency rate.

liabilities of a carrier. A Freight Forwarding company can act as an agent/ partner of a NVOCC. Apart from these major differences, all other activities of these two entities are similar. NVOCC is basically a "carrier to shippers" and "shipper to carriers".

In addition to above there are several other agencies that play a role in international trade. These are main-line-operators (MLO), multimodal transport operators (MTO), equipment suppliers etc.

Ships arriving at a port need to take permission from vessel surveyors, Mercantile Marine Departments (checks the sea worthiness of a ship), Port Health Organisation (checks health of crew that arrive along with ship or aircraft), Immigration Department (checks the passport and Visa of crew members).

Shipping Operation

There are two types of shipping operation, namely, liner operation and tramp shipping (figure 23).

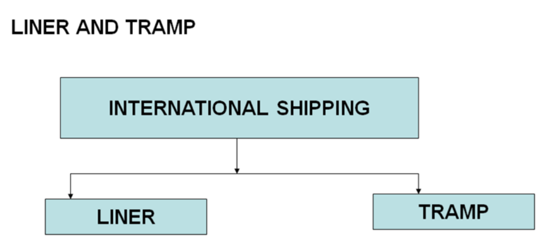
Liner operation: General cargo (break bulk) and containers move by liner ships. This has regular sailing schedule along regular routes with fixed port of calls. The liners charge tariff rates per unit space. The vessel signs a document of contract with the shipper called Bill of lading, as contract of carriage mentioning, the consignor, and consignee, port of origin and port of destination along with cargo description that is received on board. Booking of spaces is usually done through shipping agents. Liners form conferences (a form of cartel) to optimize shipping operations. A liner may opt to be outside a conference.

Liner Conference: EU Regulation 4056/86 Defines Liner Conference as

" ... A group of two or more vessel-operating carriers which provide international liner services for the carriage of cargo on a particular route or routes within specialized geographical limits and which has an agreement or arrangement, whatever its nature, within the framework of which they operate under uniform or common freight rates and any other agreed conditions with respect to provision of liner services".

Exemptions for agreements between carriers (liner conferences) granted by EC were subject to *conditions* attaching to exemption and *obligations* attaching to exemption.

Figure 23. Type of shipping operation



Consortium: Consortium Is Defined, Art. 2 (1), Regulation 823/2000 (EC) as Follows

".. An agreement between two or more vessel-operating carriers which provide international liner shipping services exclusively for the carriage of cargo, chiefly by container, relating to one or more trades, and the object of which is to bring about co-operation in the joint operation of a maritime transport service, and which improves the services that would be offered individually by each of its members in the absence of the consortium in order to rationalize their operations by means of technical, operational and/or commercial arrangements, with the exception of price fixing".

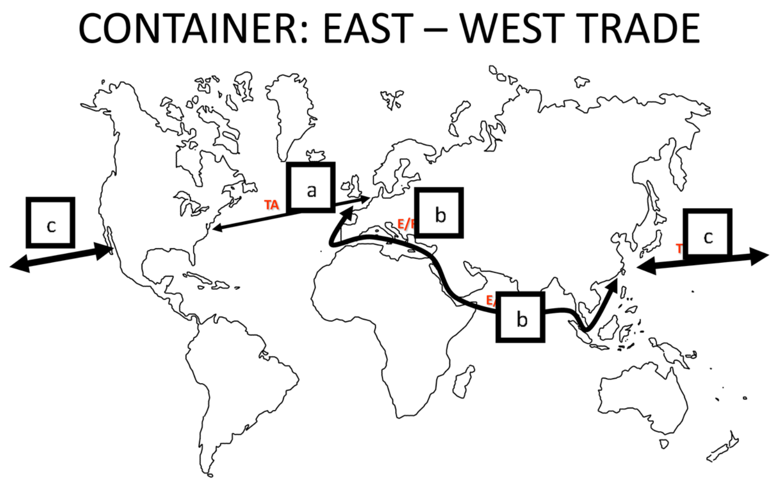
Consortia are joint ventures, global alliances and mergers. This has resulted in concentration in the liner shipping sector going up over the years. In 2010 the top 10 (ten) shipping lines take up around 80% of the world market. While in 1998 twenty (20) leading carriers in the liner sector controlled 35 per cent of the world container capacity. While concentration, by itself is not anti-competitive, higher concentration levels tend to create dominant players who may abuse their dominant position. The basic scope of consortia, subject to certain conditions, include joint operations of maritime transport services, temporary capacity adjustments, joint operation or use of port terminals, participation in one or more of the following pools: cargo, revenue, net revenue and a joint marketing structure and/or the issue of a joint bill of loading. The top ten shipping companies include:

1. Maersk Line
2. Fed Ex (Federal Express)
3. UPS (United Parcel Services)
4. MSC (Mediterranean Shipping Company)
5. Hapag Llyod
6. CMA CGM
7. Evergreen Line
8. APL
9. COSCO Container lines Americas
10. NYK (Nippon Yushen Kaisha)

Liner Routes: The liner route for container shipping includes:

1. The East- West Trade (figure 23)

Figure 24. Container liner services: east to west



a. Across Atlantic Ocean (Trans-Atlantic): Between East coast of North America and Europe
b. Across Suez Canal: Between ports of Europe to East and Far East countries.
c. Across Pacific (Trans Pacific): Between west coast of USA and ports in Pacific Ocean.

2. The Parallel Trade (figure 25)
   a. Between ports of west coast of USA to ports in Far East through Suez Canal & Panama Canal, i.e., simultaneously with east-west trade described above.
3. North-South Trade (figure 25)
   a. Ports of Europe and Africa
   b. Ports of East coast of USA to South American ports in East coast.
   c. Ports of West coast of USA to South American ports in East Coast.
   d. Ports of South America and Far east
   e. Ports of Middle East to Ports of Australia and New Zealand
   f. Ports of Australia and New Zealand to Ports of Far East

TRAMP OPERATIONS

The salient features of tramp operations are:

Figure 25. Container liner services: East to West – West to Far East

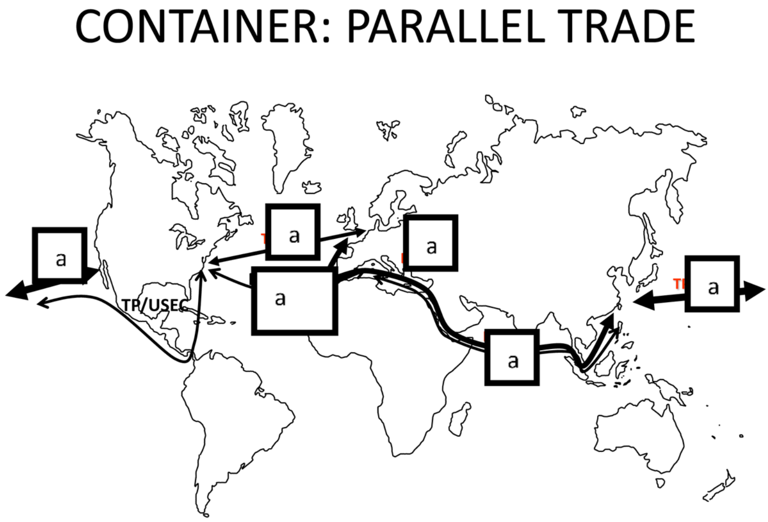
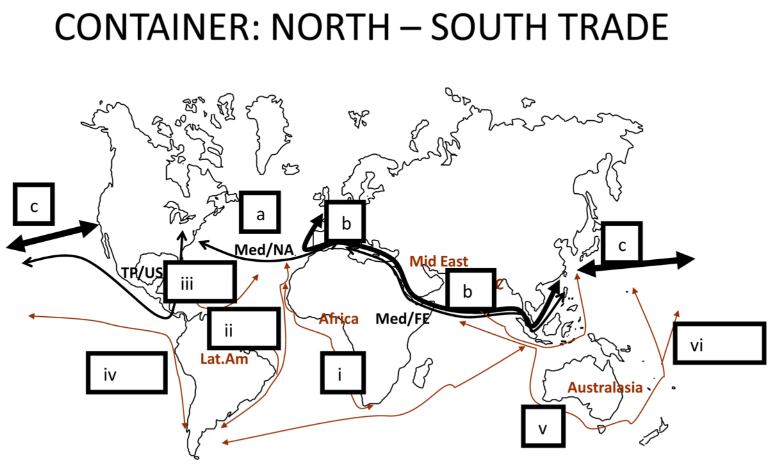


Figure 26. Container liner services: north to south



- It primarily carries bulk cargo – dry / liquid or neo-bulk cargo
- There is no fixed sailing schedule
- Tramp operations follow demand
- Charter rates are negotiable
- Document of contract is called charter party
- Free-In-Out
- The charterer and the shippers fixing vessels through agents

- Tramp shipping lines have no conference / cartel_

CHARTERING

- Chartering refers to hiring of a vessel for a particular voyage or a period of time
- A charterer may be:
  - a party without a cargo
  - a party with cargo

Charterer: A Party With a Cargo

In some cases a charterer may own cargo such as the oil companies India (Indian oil, HPCL) and employ a shipbroker to find a ship to deliver the cargo for a certain price, called freight rate who takes a vessel on charter for a specified period from the owner and then trades the ship to carry cargoes at a profit above the hire rate, or even makes a profit in a rising market by re-letting the ship out to other charterers.

Freight rates may be on a per-ton basis over a certain route (e.g. for iron ore between India and China) or alternatively may be expressed in terms of a total sum - normally in U.S. dollars - per day for the agreed duration of the charter.

Some ship owners may let their ships to charterer without cargo. This category of charter lets out the ship to party with cargo or operate the ship as liner vessel.

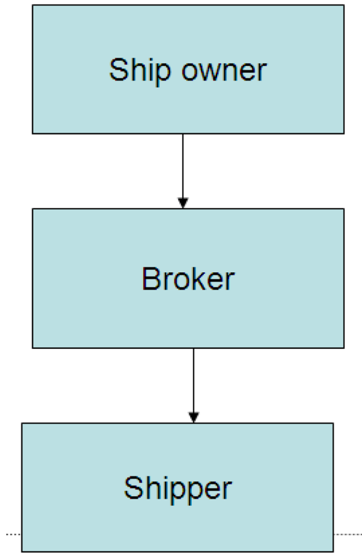
Brokers

Brokers play a crucial role in bringing together the charterer and the ship owner.

Charter Types

- A **voyage charter** refers to the hiring of a vessel for a voyage between a load port and a discharge port. The charterer pays the vessel owner on a per-ton or lump-sum basis. The owner provides for the crew and pays the port costs (excluding stevedoring), fuel costs and crew costs.

Figure 27. Role of a broker



- A **time charter** refers to the hiring of a vessel for a specific period of time. The owner deploys its crew and manages the vessel. It does the maintenance and provides for all provisions excepting fuel. The charterer selects the ports and decides on the voyages.. The charterer pays for fuel the vessel consumes, port charges, and a daily hire charge to the owner of the vessel.
- A **bareboat charter** refers to the hiring of a vessel for a specific period of time without any administration or technical maintenance being done by the ship owner. The charterer pays for all operating expenses, including fuel, crew, port expenses and hull insurance. In this case, usually, the charterer obtains title (ownership) in the hull at the end of the charter period (normally years). That is, effectively, the owners finance the purchase of the vessel.
- A **demise charter** refers to shift of the control and possession of the vessel; including the legal and financial responsibility on completion of chartering period.

Charterer Without Cargo: Roles and Functions

- A Charterer arranges for cargo and monitors operations to ensure availability of full ship load tonnage

- It monitors trend of change in freight rates. Different indices such as Baltic Dry index (BDI) measures change in cost of moving dry bulk.
- It communicates with liner agents to determine the liner rates and with brokers who are dealing with suitable tonnage in the open market

Broker: Roles and Functions

- Carries out negotiation with other broker or with ship owners
- Obtains specific authority to sign agreement of chartering
- Signs agreement as
  - Agent only – This may give rise to legal problems as to who has really entered into agreement
  - Agent for “X” firm
- keeps both owner and charterer continuously informed about:
  - Market situation and market development
  - Available cargo proposals and shipment possibilities
- Broker acts strictly within given authorities in connection with negotiations
  - Sometimes broker may have wide discretion within which to work with an absolute limit not to be exceeded
  - Signs non-disclosure of information
- A broker can be a cable broker or a competitive broker

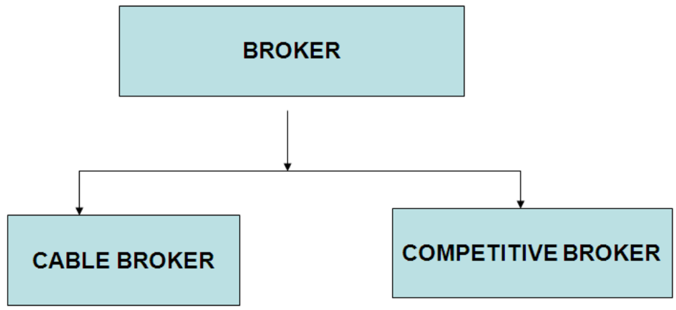
COMPETITIVE BROKER

- A competitive broker acts as middle men between the owners’ confidential broker and with broker of a suitable charterer

CABLE BROKER

- Are members of shipping centres e.g, New York and mainly list orders circulated in the shipping centres. It then distribute the lists to brokers in other shipping centres, for example – LONDON, TOKYO, OSLO, HAMBURG
- They enable **tying** together brokers, charterers and ship owners of different parts of the world. As such behave as a competitive **broker.**

Figure 28. Types of broker



AFFREIGHTMENT

- **Affreightment** is derived from the word freight and is a contract of carriage i.e., a Charter party.
- *Contract of Affreightment* (COA) is the expression usually employed to describe the contract between a *ship-owner* and the *charterer*, by which the ship-owner agrees to carry goods of the charterer in his ship, *or* to give to the charterer the use of the whole or part of the cargo-carrying space of the ship for the carriage of his goods on a specified voyage or voyages or for a specified time. The charterer on his part agrees to pay a specified price, called *freight*, for the carriage of the goods or the use of the ship.
- A charterer may be without cargo and the ship owner may let it to the charterer to take possession and control of it for a specified term and time period. The charterer who hires a ship in this way behaves as a ship-owner during the specified time. The contract by which a ship is so let may be called a charter-party; and not in true sense, a contract of affreightment. Charter-party of this kind is sometimes called a *demise of the ship.*

CHARTER PARTY

Depending on the type of ship and the type of charter, normally a standard contract form called a charter party is used to record the exact rate, duration and terms agreed between the ship-owner and the charterer.

Difference Between Charter Party and Bill of Lading

1. Charter party is a contract between a ship-owner and charterer with cargo or without cargo. It represents the hire of tonnage space; whereas the Bill of lading is the legal document that serves as a proof of the actual shipment/ loading of goods. It therefore manifests the implementing evidence of the contract of affreightment.
2. The charter party precedes the bill of lading. However in liner shipping there may not be a contract of affreightment with the shipper but there has to be a bill of lading. In this case the announcement of the ship owner to sail in desired voyage is followed by booking of space by the shipper and loading of cargo. That is, a bill of lading serves as a charter party and also serves as a proof of loading, meaning a written confirmation of the COA.
3. Charter party is a gestation agreement which means that the contract is signed before it is executed whereas bill of lading is signed after the goods have been loaded, implying that it is an actual agreement.

Charter Party: Issues

- Country and court of law to be decided for settlement of disputes
- Arbitration – arbitrators and umpire for settlement of disputes. Arbitrators are listed with international chambers of commerce / comte maritime international (cmi).
- Court or arbitration: To decide which mode to be chosen for settlement of disputes

Arbitration is preferred because of following reasons:
It is low cost, faster and helps in maintaining secrecy.

- Evidence: Availability of evidence in shipping is difficult to obtain. Legal principles concerning evidence and the burden of proof are highly complex. The parties may agree on appointment of a common independent surveyor & similar clauses
- Format of charter party: There are standard formats such as Bimco (Baltic & International Maritime Council) format.

Charter Party Contract: Contents

- The identity
- Substitution of owner or charterer
- Charter time – subletting
- Vessel – nomination, identity & substitution
- Vessel's trading limits
- Seaworthiness from
  - Technical point of view
  - Cargo-worthiness
  - Seaworthiness for the intended voyage
- Lay / can
  - Lay: lay time not to commence before i.e, time after which chartering will commence
  - Can: cancelling clause – on account of delay, not arrived or delivered (baltime clause) / ready (gencon clause) or time to cancel say 48 hours before arrival (gencon clause)
- War clause: Defines the responsibility of the charterer in event of loss due to war
- Currency clause: Defines the manner freight would vary when currency exchange rates fluctuates
- Escalation clause: Defines the manner freight would vary when fuel cost increases
- Other clauses for change of costs
- Exception clauses
- Arrest clauses: Defines the responsibility of the charterer in event of loss due arrest of crew
- Collision: Defines the responsibility of the charterer in event of collision of vessel
- Towage & salvage: Defines the responsibility of the charterer regarding recovery of vessel that gets grounded or sinks

Baltic Dry Index (BDI)

- It is an index issued daily by the London-based Baltic Exchange. It provides an assessment of the price of moving the major raw materials by sea. The index covers for various types of vessels in terms of size namely Handymax, Supramax, Panamax and Capesize dry bulk carriers. This index is computed based on cost of booking goods mainly raw materials such as coal, iron ore and grain in around 26 shipping routes measured on a time charter and voyage basis.

- The index can be accessed on a subscription basis directly from the Baltic Exchange as well as from major financial information and news services such as Thomson Reuters and Bloomberg L.P..
- The index measures the demand for shipping capacity versus the supply of dry bulk carriers. The demand for shipping varies with the amount of cargo that is being traded or moved in various markets (supply and demand).
- **BDI - a leading economic indicator: D**ry bulk primarily consists of raw materials (inputs), such as cement, iron ore, coal, fertilizers etc., to the production of intermediate or finished goods, such as concrete, electricity, steel, and food. Upward movement of the index indicates future economic growth and production. Hence is termed a leading economic indicator because it predicts future economic activity.
- As it indicates the assessment of the price of moving the major raw materials by sea, it gives insights into the highly opaque and diffused shipping market also serve as the barometer of the volume of global trade – irrespective of political and other issues.

Bills of Lading

- It is a document signed by the master or agent for the ship-owner, acknowledging the receipt of goods and describing the terms upon which it is to be carried.
- In liner shipping it assumes a triple identity, namely, property title, cargo receipt and carriage contract.
- It originated as a bill (account) presented to shippers for all the charges incurred with his cargo until properly secured and stowed on board. It evolved from a proof that cargo expenses were paid, to a **proof that the cargo was really on board** the ship and thus become a negotiable property title.
- In tramp shipping, bill of lading is termed as charter party bill of lading.

Humanitarian Logistics

- So far the logistics discussion was focussed on commercial movement of goods. The principles related to commercial logistics do not hold good in case of disaster management. It includes relief delivery, repair equipment delivery, movement of rescuers and the injured. Thus the algoritms for commercial routing of goods are not applicable for humanitarian logistics (Özdamar, & Ertem, 2015). As in case of commercial supply chain, humanitarian logistics also need to be integrated with modern information technology. However, the information content and its validity varies greatly between these two logistics systems, The primary focus in humanitarian logistics is relief which implies immediate supply in right quantity at right place for right person where information on these aspects are very less known in advance. Besides, the normal routes for movement of supplies may also be disrupted and hence different routing algorithms are required to be implemented. The location of sites for disaster managemnt is based on the criteria of maximum coverage of medical and relief needs in the affected zones. In addition, the manpower (such as medical personnel) deployment alongwith materials also need to be maximized (Yi, & Özdamar, 2007). The reverse logistics for evacuation of injured is instantaneous and needs on the spot decisions. The scale of operation is uncertain and therefore building up inventory or assets is difficult. The post relief management include debris collection and rehabilitation where the objective function is different from commercial logistics.

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Conclusion

So far we observed that supply chain management needs to be understood from different perspectives. Its planning and execution require understanding of the industry, the firm and its environment. Most of the research works, carried out so far, consider one or some of the dimensions for improved decision making.

The following areas are proposed for further research:

1. Integration of firms' own capacity with out-sourced capacity to meet challenges arising out of change in variety; variability in demand and volatility in cost of resources:

So far literature suggests that firms need to outsource those activities where it lacks competency or capacity to do the same. However, the competency and capacity of the outsourced firm vary with its own (organisation) and product life cycle. Hence, there may be a need to understand the outsourcing lifecycle as well. For example, many companies such as Amazon which outsourced its warehousing activities initially started owing warehouses in long run.

2. A strategic framework to meet challenges arising out of inter-state relations in line with recent trade war between US and China.

The recent imposition of exorbitant import tariff, by US, on Chinese firms has led these firms to suffer sudden loses and left the US buyers to re-design their sourcing strategy. US have imposed such measures in view of its growing debt, joblessness and IPR issues. Hence firms need to have a mechanism to study the markets in terms of their internal dynamics causing disruption of supply chains.

3. Development of metrics to identify a possibility of bull whip effect or snow ball effect or a likely disruption in immediate future based on recent events, trends and stakeholders' behaviour.

Many a times the deviation in expected behaviour of supply network of a firm goes un-noticed till there are stoppages, closures or breakdown of supply chain(s). A framework to identify likelihood of bull whip or snowball effect or any disruption in supply chain based on trends and certain lead-metrics may be developed.

4. Manpower planning considering the three dimensions of sustainability, especially the social and economic dimensions.

The GRI framework suggests that firms should encourage employees to avail parental leaves by incorporating such rules and ensure their retention after the employees return to work. In this competitive world, cost of production is a very crucial component and requires reduction of overheads. As such to have a lean enterprise firms may not be able to afford redundancy in their staff strength and at the same time, to be sustainable socially, it needs to incorporate the suggestions made by GRI. Thus, there is a need to design operation and supply chain manpower plan considering the three dimensions of sustainability.

5. Review of existing literature on supply chain sustainability index to propose improvement in light with recent trends such as driverless electric vehicles vis-à-vis accidents and limits to supply of lithium and cobalt; unethical practices by senior executives of Samsung and Nissan; arrest of Huwawei executive in China, imposition of tariff by US and exit of Britain from EU.
6. Study of the relevance of resource-based-view (RBV) in supply chain, especially in light of disagreements between Barney (2012) and two other authors (Ramsay, 2001; Hunt and Davis, 2008)
7. Use of artificial intelligence in predicting supply chain behaviour of a firm:

The supply chain behaviour is dependent on various factors, both quantitative and qualitative. In today's world, with the availability of big data, application of artificial intelligence tools and techniques is expected to give deeper insights to the cause of behaviour of supply networks of a firm.

8. A review of factors affecting container freight rates:

Hummels (2010) described different factors such as distance, volume and value of goods shipped that may affect shipping cost. At the same time the container shipping industry witnessed negative freight (spot) rates in recent past (UNCTAD, 2017) inspite of the fact the value of shipment and distance did not reduce. Hence, there is need to determine the dimensions and factors (and their relationships) that explains such as wayward movement of container freight rates.

9. Development of a framework to decide between different options of sourcing of raw materials viz., strategic partnership, online bidding and commodity trading:

The non-availability of commodity and volatility of its prices can disrupt a firms' supply chain. The study of stochastic movement of commodity prices can help detecting points from wherein a supply chain manager may opt for strategic partnership rather than resorting to spot purchases. These studies can lead to development of a decision making framework related to sourcing.

10. Development of ontology on multimodal transportation for identification of defects in multimodal logistics chain:

Ontology formally represents knowledge about a domain in a structured and computer readable way (Gruber, 1993). Daniele & Pires (2013), opined that ontologies enable common understanding of concepts and have been acknowledged as a powerful means to foster collaboration, both within the boundaries of an individual enterprise (intra-enterprise) as outside these boundaries (inter-enterprise). The authors concluded that the use of ontologies can be beneficial for enterprise interoperability in the logistics domain, to improve communication and foster knowledge reuse, to facilitate the integration of existing systems and to support the development process of software solutions. Leukel and Kim (2008) used an ontology based approach for management of supply chain and concluded that top level ontologies include process class having subclasses namely, plan, source, make deliver, return and the metrics.

Ontology of multimodal transportation logistics may be developed for effective planning and minimisation of errors.

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