International Journal of Business and Applied Social Science Vol.1, No.1, December/2015

Supply Chain Management Research Models: An Overview of the Current Literature

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ABSTRACT:

This study conducts a thorough overview of the current literature on the models of supply chain management research in the major literature in management and decision science and classifies them into three categories. Such categorization provides a clear and precise view of the supply chain models literature, based on which we can find the gaps in the current research.

INTRODUCTION:

As Ganeshan et al. (1999) point out; efforts to describe and explain supply chain management (SCM) have recently led to a plethora of research and writing in this field. At the same time, the level of attention to SCM received in business practices nowadays also heavily influences the growing interest in SCM research. Several researchers have attempted to provide some taxonomies and frameworks to present both practitioners and academics cohesive information that explains the SCM concept and emphasizes the variety of research work being accomplished in this area (See Bowersox, 1969; Laugley, 1992; Bechtel and Jayaram, 1997; Ganeshan, et al., 1999; and Tan, 2000). These authors, among others, have reviewed relevant streams of thoughts in SCM research, provided integrative frameworks to help design and manage supply chains, or categorized the existing research on SMC to offer organized information for other researchers.

Despite the efforts of previous authors, we believe that the growing and rich literature in SCM warrants a close examination of SCM models published in major operations research and management journals. By doing so, we will be able to better understand what the areas are studied and how these areas of study are modeled, and synthesize future directions of SCM research. We classify these models found in major academic journals into three categories, namely, contracting relationship models, information models, operational relationship models.

DEFINE THE SUPPLY CHAIN:

Supply chains have existed ever since business has been organized to bring products and services to customers (Kumar, 2001). Many variations are found in literature on the same theme when defining a supply chain. There are two major views of supply chain in the literature. One school takes the system view which can be found in Houlihan (1985), Jones and Riley (1984), Stevens (1989), Scott and Westbrook (1991), and Lamming (1996). This theme of thought believes that supply chain is a system of suppliers, manufacturers, distributors, retailers, and customers where materials flow downstream from suppliers to customers and information flows in both directions. As Mentzer et al. (2001) put it: a supply chain is a set of entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer.

Other authors view supply chain as a network of organizations and their associated activities that work together, usually in a sequential manner, to produce value for the consumer (Kumar, 2001). Swaminathan et al. (1998) completes this network view by defining a supply chain as a network of autonomous or semiautonomous business entities collectively responsible for procurement, manufacturing and distribution activities associated with one or more families of related products.

Both views have accurately described the entities, activities, and missions of a supply chain from different perspectives and each has its own emphasis. For the system view, it focuses on the processes of making from raw material to final products and how these products are handed to customers in an effective and efficient way, as well as how information is passed within this system to support those processes. While the network view aims to explain the supply chain through the inter relations and inter actions between each entities involved. These entities are highly interdependent when it comes to improving performance of the supply chain in terms of objectives such as on time delivery, quality assurance, and cost minimization (Swaminathan et al., 1998). Authors with the latter view identify different functions (groups of entities working closely) in a supply chain such as, procurement of material, transformation of material to intermediate and finished products, and distribution of finished products to customers, etc. (Lee and Billington, 1993).

SCM DEFINED:

The term SCM appears to have originated in the early 1980s when Oliver and Webber (1982) discuss the potential benefits of strategically integrating the internal business functions of purchasing, manufacturing, sales and distribution (Harland, 1996). The idea of SCM emerges from logistics management integration, which shifts the focus from materials management to the movement of material throughout the firm in an organic and systemic way to greatly improve the effectiveness and the efficiency of the operation (La Londe ad Masters, 1994).

SCM is different from logistics management, as often confused by practitioners and academics. According to the definition given by the Council of Supply Chain Management Professionals (CSCMP), "Logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverses flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements." (CSCMP, 2005) The transition of logistics (materials) management to SCM is a result that what were hitherto considered mere logistics problems have emerged as much more significant issues of strategic management. Houlihan (1985) studies firms in a variety of industries in the USA, Japan and Western Europe and finds that the traditional approach of seeking tradeoffs among the various conflicting objectives of key functions such as purchasing, production, distribution and sales, along the supply chain no longer worked very well and calls for a new approach, which is SCM.

SCM consists of a decision support system, which is concerned with determining supply, production and stock levels in raw materials, subassemblies at different levels of the given Bills of Material (BoM), end products and information exchange through (possibly) a set of factories, depots and dealer centers of a given production and service network to meet fluctuating demand requirements (Escudero et al., 1999). The necessity of managing the supply chain is mainly contributed by three factors, as indicated by Kumar (2001). These factors include: first, customers become more cost and value conscious and demand more, varied, often individualized value from the supply chain; second, the modern information and communication technologies enable the firms to obtain an overview of the entire supply chain so that they can redesign and manage it to meet this demand; finally, the emergence of global markets and global sourcing have stretched these supply chains over intercontinental distances. As a result, the accumulated demand variety, uncertainty, costs, distances, and time lags on a global scale make it even more imperative that these long chains be managed efficiently and effectively. Consequently the focus shifted from the competitive advantage of firms to competitive advantages of entire supply chains. The definitions of SCM differ across authors. For examples, Monczka et al. believe that SCM is a concept "whose primary object is to integrate and manage the sourcing, flow, and control of materials using a total systems perspective across multiple functions and multiple tiers of suppliers." Jones and Riley (1995) state that SCM deals with the total flow of material from suppliers through end users. Cooper et al. (1997) define SCM as an integrative philosophy to manage the total flow of a distribution channel from supplier to the ultimate user. Other examples of definitions can be found in La Londe and Masters (1994), Stevens (1998), and Houlihan (1985). These definitions can be classified into three categories: a management philosophy, implementation of a management philosophy, and a set of management processes. Put them together, Mentzer et al. (2001) give a definition: SCM is "the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across business within the supply chain, for the purposes of improving the long-term performance for the individual companies and the supply chain as a whole."

It is worthwhile to mention that owing to the rapid advances of information and communication technology, the most recent development in the concept of SCM includes the Internet as one of the key influential factors. The e-commerce, business-to-business (B2B) and business-to-customers (B2C) through the Internet, is transforming organizations and organizational processes and creating new opportunities and challenges for domestic and international companies and their supply chains as the Internet is enabling greater integration of businesses and a blurring of traditional organizational boundaries (Bakos, 1998, Hitt et al., 1999, Lancioni et al., 2000, Overby and Min 2001, Johnson and Whang, 2002). This transformation dramatically changes the relationships between the entities in a supply chain and the perception of the traditional SCM. There is at this moment not a definition of this new SCM from the literature available. As noticed by Lancioni et al. (2000), to date, there have been few academic studies examining the development and use of the Internet in SCM.

For the purpose of this dissertation, we give a working definition of SCM which is built on the Mentzer et al. (2001)'s as well as others definition.

> *SCM is the system that aims coordinate the interrelations and interactions among networked business functions, to manage the information flows between these business functions, and to provide strategic and tactical decisions in a effective and efficient way with the help of available information and communication technologies within a particular company and across business within the supply chain, for the purposes of improving the long-term performance for the individual companies and the supply chain as a whole.*

CATEGRIES OF SCM MODELS:

The objective of classifying SCM models is to provide a clear overview of the types of models that have been researched in the current major literature organized in the way that we can decide and formulate a model for the dissertation to work from.

There are only a small number of papers that classify the research in SCM. Meixell and Gargeya (2005) review decision support models for the design of global supply chains and assess the fit between the research literature in this area and the practical issue of global supply chain design. Their review is thorough and well organized. However, it does not fit the purpose of our review for the following reasons:

1) The review focuses on models for designing a supply chain rather than the management of the supply chains.
2) It investigates the models based on the years that they are developed, i.e., period prior to 1990, between 1991 and 1995, from 1996 to 2000, and years after 2000. This would not give us a clear view of the focuses of the models.
3) It looks into the models by using four dimensions-decision variables, performance measurements, supply chain integration, and globalization considerations.

4) It does not scrutinize the models based on the problems that each model is trying to solve.

Ganeshan et al. (1999) classify the SCM research into three broad perspectives; competitive strategy, firm focused tactics, and operational efficiencies. These perspectives are further divided into many subcategories. The authors try to give a broad review of updated chart of the historical development of SCM and their focus is on much broader field in SCM research and has not specifically synthesized the models in SCM. Therefore it will not fit the purpose of this paper, either.

Many models have been developed in the SCM literature. Authors address various issues from different aspects of SCM. In this review, we group their focuses into three categories, which are information models, contracting relationship models, and operational relationship models. This categorization is broad and based on the following questions that each categorical model needs to answer:

- What is the focus that the target model is trying to place on? Is it on information or relationships (contracting or operational) issues? Each type of modeling has its own specific questions as described in the following explanations.

- **Information models:**

  - What type of information is the focus of the study? One of the common information often addressed in the literature, for example, is in a typical two echelon supply chain model the demand information to examine the bullwhip effect (Lee et al. 1997). Other information may include the sales data (real time or batch mode), inventory level information, delivery information, etc. Readers who are interested in more detailed description of the types of information may be referred to Lee and Whang (2000).

  - How information is handled in SCM? Such studies include the use of traditional or electronic data exchange technology to make the information available when needed. Some of common technology includes EDI (Electronic Data Interchange), Intranet, Internet, VPN, and many others.

  - What are the roles of information in SCM modeling? Information of different types may play different roles and the sharing of different information may have different impacts to the supply chain performance in magnitude as well as levels.

  - How does the model deal with information distortion, information asymmetry, information sharing, and other phenomenon found in SCM? What are the impacts and how does the model manage to cope with them?

- **Contracting Relationship models:**

  - What are the relationships that SCM modeling is interested in-manufacturer/supplier retailer, retailer customer, or others?

  - How does the contract affect the relationship between the entities in SCM and how does a model map this relationship and find the solution to the problem if there is any?

  - How does a model that deal with the supplier selection issues?

- **Operational Relationship models:**
  - What are the capacity, pricing, or inventory policies and how can a model find the optimal one?
  - What are the variables that a model identifies to work with the capacity, pricing, or inventory problems?

- ✓ How does the uncertainty in demand impact the decisions on capacity choice and allocation, pricing, and inventory policies? What are the models examine them and how do these models work?

This review focuses on the model-based literature and we conducted a search using library databases covering the major journals in management science and operations management, such as *Management Science, Operations Research, European Journal of Operational Research, Decision Sciences, the Journal of Supply Chain Management, Decision Support Systems*, etc. Research papers found are grouped into four categories, each of which has subcategories. Figure 1 provides a guideline of how this classification is structured in this paper. The following section gives detailed descriptions of each category.

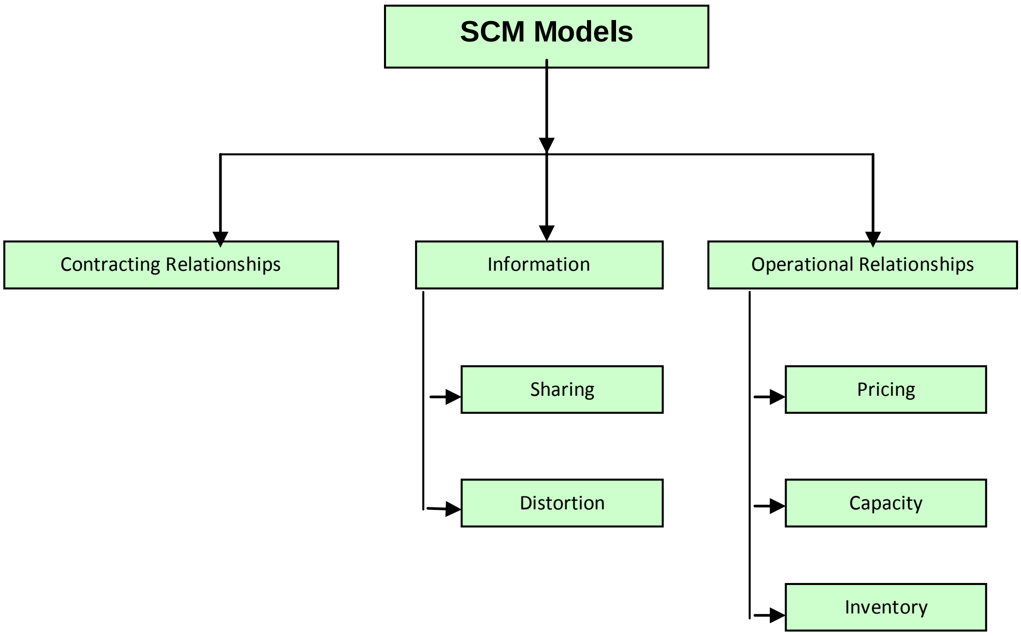

Figure 1: SCM Models Categorization Structure

MODELS ON CONTRACTING RELATIONSHIPS:

Harland (1996) views SCM as the management of supply relationships, i.e., "an intermediate type of relationship within a spectrum ranging from integrated hierarchy (vertical integration) to pure market." This perspective of SCM has as its foundations an industrial organization and contract view of the firm as a nexus of contracts (Aoki, 1990). Models are found to address the relationship problems related to contracting, incentives, and supplier selection.

Hui and Beath (2001) point out that the natural artifact to analyze the inter-organizational relationship in modern industrial organization is the contract. Contracts not only serve as simply a list of rules, but also define the tone and nature of the relationship. The contract has become an exemplary subject for studying SCM because it is the written artifact that results from firms in a supply chain trying to understand the nature of the relationship (Walden, 2002).

Corbett and DeCroix (2001) study how contracts affect consumption of indirect materials, which are consumed during the production process but do not become part of the final product, by influencing the amount of effort supplier and customer exert to reduce that consumption. The authors create a mathematical model to analyze the impact of shared savings contracts on channel profits and material consumption assuming that the variable component is linear in the quantity of indirect material used. While such linear contracts can yield higher profits as well as possibly lower consumption, the resulting equilibrium effort levels are generally not channel-optimal outcome since such contracts do not necessarily lead to lower consumption.

Corbett et al. (2005) further the study in the stream by addressing the questions of determining the optimal shared-savings contract from the supplier's perspective, other than the channel perspective adopted in Corbett and DeCroix (2001), in a more general setting. The authors use the double moral hazard framework, in which both parties (consumer and supplier) decide how much effort to exert by trading off the cost of their effort against the benefits that they will obtain from reduced consumption. The model they use extends the double moral hazard literature to allow for a broader class of cost of effort functions, including the linear functions found in practice, and shows that the supplier's optimal contract still consists of a fixed part and a variable part which is linear in consumption.

Similarly, the research of Tsay (1999) considers a supply chain consisting of two independent agents, a supplier (e.g., a manufacturer) and its customer (e.g., a retailer). He finds that the retailer, who serves an uncertain market demand and typically provides a planning forecast of its intended purchase, has incentive to initially over forecast before eventually purchasing a lesser quantity. The supplier must in turn anticipate such behavior in its production quantity decision. This individually rational behavior results in an inefficient supply chain. The author applies the quantity flexibility (QF) contract which couples the retailer's commitment to purchase no less than a certain percentage below the forecast with the supplier's guarantee to deliver up to a certain percentage above. An equilibrium solution is given and the efficiency of QF contract is evaluated through numerical analysis. Under certain conditions, this method can allocate the costs of market demand uncertainty so as to lead the individually motivated supplier and customer (retailer) to the system wide optimal outcome.

In the same line of research, instead of focusing on using the quantity flexibility contracts, Eppen and Iyer (1997) study the backup agreements (contracts) between a catalog company and manufacturers a scheme to provide upstream sourcing flexibility for fashion merchandise. As authors define, a backup agreement states that if the catalog company commits to a number of units for the season, the manufacturer holds back a constant fraction of the commitment and delivers the remaining units before the stat of the fashion season. After observing early demands, the catalog company can order up this backup quantity for the original purchase cost and receive quick delivery but will pay a penalty cost for any of the backup units it does not buy. They use a dynamic programming model to derive the form of the optimal polity. The model is evaluated by performing a retrospective parallel test on the data obtained from a catalog company and they conclude that backup agreements can benefit both the retailer and the manufacturer and the adjusting the order commitment in response to the offered percentage to hold by the retailer can have a significant impact on expected profit.

Cachon and Lariviere (2001) compare revenue sharing contracts with other types of contracts we have mentioned above, among others. They found the revenue sharing contracts are at least equivalent with, and most times superior to other types of contracts. Their base model has a supplier selling to a single retailer. The retailer makes two decisions that determine the total revenue generated over a single selling period: the number of units to purchase form a supplier and the retail price. The functions derived show that revenue sharing coordinates this supply chain; i.e., the retailer chooses supply chain optimal actions (quantity and price) and the supply chain's profit can be arbitrarily divided between the firms. Further, a single revenue sharing contract can coordinate a supply chain with multiple non-competing retailers even if the retailers have different revenue functions. However, revenue sharing generally does not coordinate competing retailers when each retailer's revenue depends on its quantity, its price, and the actions of the other retailers.

Cachon (2004) looks into the above issues from inventory risk management perspective. He considers, as others, a supply chain with one risk neutral supplier buying a product one risk neutral retailer and demand for the product being stochastic over a single selling season, and studies how the allocation of inventory risk through various types of contracts influences a supply chain's performance and its division of profit. Three types of wholesale price contracts are modeled. With the push contract, the retailer must pre book inventory and the supply only produces the retailer's pre book quantity, therefore, all inventory risk is pushed onto the retailer. In contrast, with the pull contract, the retailer pulls inventory form the supplier with at once orders, thereby leaving the supplier with all inventory risk. The third type is the advance-purchase discounts, which blends both push and pull by having two wholesale prices. The retailer may pre book some inventory at a lower price than at once wholesale price to bear the risk on that inventory; and the supplier may produce additional inventory in anticipation of at once orders to bear the risk on that additional production. Cachon (2004)'s research shows that the allocation of inventory risk matters for supply chain efficiency even if firms are risk neutral. It is also shown that without changing the wholesale price, merely shifting the inventory risk from one firm to another can improve supply chain efficiency and increase profit at both firms. In addition, if the firms are willing to share inventory risk via advance purchase discounts, then supply chain coordination is achievable with any division of the supply chain's profit.

A more recent study on shared demand forecasts in a supply chain is conducted by Cachon and Lariviere (2001). The authors identify three key components of a software development contract product definition, intellectual property protection and payment. They develop a game-theoretic model to incorporate incentive and information issues associated with the payment structure in software contracting. They derive the structure of a viable contract that aligns the incentives of the contracting parties and produces the same efficient equilibrium outcome as in in-house development. However this model has several drawbacks because of some unrealistic assumptions, such as players in the game are risk neutral; the design will not change in the middle of the development; and it assumes that the value of a design is exactly determined based on the prototype.

Baiman et al (2001) model the contracting relationship between a supplier and a buyer, which not necessary is a retailer. However, their focus is on the buyer outsourcing the production of some part to the supplier. They study the interactive effect of the performance metric chosen and the architecture of the product being manufactured on the incentive efficiency of the supply chain. The performance matrices studied are the occurrence of an external (final product fails after sale) and /or internal failure (defective product supplied by the supplier).

Contracting relationship is one of the most important artifacts in SCM. Number of literature can be found and we pick several representative ones to demonstrate the main stream models that have been studied to date.

MODELS ON INFORMATION:

SCM is concerned with coordination of independent enterprises in order to improve the performance through the whole supply chain by considering their individual needs. One of the important issues of the coordination is to manage the product and production information among them (Lau et al., 2004). The models that study the management of information in supply chain deal mainly with the issues as related to information sharing and information distortion.

- **MODELS ON INFORMATION SHARING:**

Research on SCM information modeling has different focus as stated above. However, literature shows that the emphasis of this theme of research heavily leans to information sharing. The most commonly asked questions are, "What is the value of information and information sharing?" "What and how information are shared in supply chain?" and "How do we model the information sharing in supply chain?" The answers to these questions are the models as summarized in the following text. Table 2 gives a summary of the models on information sharing.

Gavirneni et al. (1999), Lee et al. (2000), and Raghunathan (2001) model the value of information and information sharing by incorporate information flow between a supplier and a retailer in a typical two-echelon supply chain. Gavirneni et al. (1999)'s model captures the capacitated setting of a supply chain. They considers three situations with three models: 1) a traditional model where there is no information to the supplier prior to a demand to him except for past data; 2) the supplier knows the (s, S) policy (i.e., at the supplier retailer interface there is an implicit fixed ordering cost) used by the retailer as well as the end-item demand distribution; and 3) the supplier has full information about the state of the retailer. The authors' computational results of the three models show that information is always beneficial but the degrees may vary. That is, in the case that end demand variance is high, or the value of $\Delta = S - s$ is very high or very low, the benefits of additional information is not as great as in the other case when end item variance is moderate and the value of Δ is not extreme.

While the research by Gavirneni et al.(1999) is based on demand processes that are independent and identically distributed over time; thus the benefit of information sharing lies in the supply's capability to react to the retailer's needs via the knowledge of the retailer's inventory levels to help reduce uncertainties in the demand process faced by the supplier, Lee et al. (2000) examine a different situation in which the underlying demand process is a simple auto correlated AR(1) process, the supply can benefit from obtaining information about the demand from the retailer because it would enable the supply to derive a more accurate forecast of future orders placed by the retailer. The analytical and numerical analyses show that the supplier can benefit from inventory reduction and cost reduction with information sharing. In addition, the authors find that under the conditions that underlying demand is highly correlated over time, highly variable, or when the lead time is long, the supplier obtains larger benefits.

However, the subsequent research by Raghunathan (2001) reaches a different result. He finds that the supplier's benefit is insignificant when the parameters of the AR (1) process are known to both parties, as in Lee et al. (2000). The key reason for the discrepancy is that Lee et al. (2000) assume that the supplier also uses an AR (1) process to forecast the retailer order quantity. Nonetheless, the supplier can reduce the variance of its forecast further by using ht entire order history to which it has access. Thus, when intelligent use of the already available internal information (order history) suffices, there is no need to invest in inter-organizational systems for information sharing. However, the AR (1) demands process of Lee et al. (2000) may be too simplified. Some retailer actions such as promotion, price reduction, and advertising taken during next period may change the AR (1) demand process over time. In this case, if the retailer actions are independent of each other, the information sharing will still be valuable because the retailer actions cannot be inferred by the supplier using order history. In a more general case, the normality assumption of the AR (1) demands model of Lee et al. (2000) may also be over simplified.

A slightly different research from Gavirneni et al. (1999) and Lee et al. (2000) is by Cachon and Fisher (2000), who study the value of sharing demand and inventory data in a model with one supplier, N identical retailers, and stationary stochastic consumer demand. Cachon and Fisher (2000) compare a traditional information policy that does not use shared information with a full information policy that does exploit shared information. Both numerical and simulation based analysis show that the latter case offers cost savings. In addition to the contributions offered by the other authors, Cachon and Fisher (2000) developed a lower bound over all feasible policies. They find that the cost difference between the traditional information policy and the lower bound is an upper bound on the value of information sharing. The more interesting result is that by contrasting the value of information sharing with the benefits of information technology (IT), i.e., faster and cheaper order processing, the authors conclude that implementing IT to accelerate and smooth the physical flow of goods through a supply chain is significantly more valuable than using IT to expand the flow of information. This view is supported by the research of Srinivasan et al. (1994), who use baseline logit model to explore the relationship between shipping discrepancies and two factors (JIT schedules and EDI integration) that capture the level of vertical information integration between a firm and its suppliers. This study suggests that gains from JIT systems can be substantially increased by modern information technology support.

Although information sharing has the potential to dramatically improve supply chain performance, some research find this may not always be true. A recent paper by Terwiesch et al. (2005) studies information sharing from the demand forecast perspective. The authors find that the retailer's forecasting behavior can be characterized by the frequency and magnitude of forecast revisions it requests (forecast volatility) as well as by the fraction of orders that are forecasted but never actually purchased (forecast inflation). They model the evolution of a soft order to a firm order and ultimately to a delivered piece of equipment in the form of a two-stage process. The first state captures the fact that soft orders can either end up as firm orders, that is, the buyer places an order, or be cancelled. In the second state, a firm order will see a delivery time. They find that forecast sharing does not provide benefits to the performance of the supply chain. This may be explained from two perspectives. As for the supplier, the forces that prevent effective forecast sharing are forecast volatility and forecast inflation and is not willing to allocate production capacity to the soft order that has changed multiple times and penalizes the buyer for inflated forecasts through longer delivery times; buyer will provide more aggressive forecasts to those suppliers that have failed to deliver previous orders on time. This follows the logic of the repeated prisoner's dilemma game and establishes that both retailer and supplier apply a tit-for-tat strategy. The authors call for research to analyze supply chain coordination in repeated game settings and to overcome the forecast volatility problem.

Most of the research as reviewed above study the models that apply to information sharing for inter-organizational supply chain management and very few has looked into the intra-organizational supply chain. Unlike others, Chen considers a supply chain whose members are divisions of the same firm. Under the assumption that he division managers share a common goal to optimize the overall performance of the supply chain, which is difficult to achieve in an inter organizational supply chain, the author develops a team solution that reveals that information lead times in determining the optimal replenishment strategies offer cost savings.

-INFORMATION DISTORTION: THE BULLWHIP EFFECT:

As noted in the previous text, on important mechanism for coordination in a supply chain is the information flows among members of the supply chain. These information flows have a direct impact on the production scheduling, inventory control and delivery plans of individual members in the supply chain. Several researchers (Forrester, 1959, Sterman, 1989, Lee et al. 1997, etc.) in management science notice that there exists systematic distortion in demand information as it is passed along the supply chain in the form of orders. This information distortion is called bullwhip effect.

The "bullwhip effect" was first coined by Lee et al. (1997) in their earlier working paper on the same topic. This is a phenomenon where orders to the supplier tend to have larger variance than sales to the buyer (i.e. demand distortion), and the distortion propagates upstream in a amplified form (i.e., variance amplification). Evidence of the bullwhip effect is reported by Sterman (1989) in an inventory management experimental context called "Beer Distribution Game." This experiment, under the linear cost structure, shows that the variances of orders amplify as one move up in the supply chain. The author interprets the phenomenon as a consequence of players' systematic irrational behavior, or "misperceptions of feedback." Another evidence is reported by Kahn (1987), who models inventory behavior that incorporates stock outs, backlogs, and serially correlated demand in a supply chain. He reports that the variance of production will exceed the variance of sales even in the absence of movements in productivity or costs. Lee et al. (1997) in their study develop mathematical models of supply chain that capture essential aspects of the institutional structure and optimizing behaviors of members who are assumed to be rational and optimizing. These assumptions are important because the authors employ mathematical models to explain the outcome of rational decision making, as opposed to deriving an optimal decision rule for managers.

There are four causes of bullwhip effect, namely, demand signal processing, the rationing game, order batching, and price variations. Lee at al. (1997) use four models to investigate the effects of the four causes that lead to systematic distortions of information in the order replenishment transactions of a standard supply chain. Table 3 lays out the mathematical models from their research in addition to the research by others in this filed.

At the same time, Metters (1997) uses a classical approach to determine the optimal policies by dynamic programming as the model used by Zipkin (1989). He concludes that a lack of inter organizational communication combined with large time lags between receipt and transmittal of information are at the root of the problem.

Cachon (1999) models the supply chain demand variability using the same settings as Lee et al. (1997) with one supplier, N retailers, and stochastic demand. In addition to the findings of lee et al. (1997), the author shows that the supplier's demand variance will generally decline as the retailers; order interval is lengthened or as their batch size is increased. By reducing supplier demand variance with scheduled ordering policies, the total supply chain costs can be lowered.

Another important research on bullwhip effect is by Chen et al. (2000). Beginning with a simple supply chain model with one retailer and one supplier, the authors quantify the bullwhip effect by considering two of the factors: demand forecasting and order lead times. They show that if a retailer periodically updates the mean and variance of demand based on observed customer demand data, then the variance of the orders placed by the retailer will be greater than the variance of demand. The authors then extend the results to multiple stage supply chains and find that providing each stage of the supply chain with complete access to customer (centralized) demand information can significantly reduce this increase in variability. However, the bullwhip effect cannot be eliminated fully as noticed by other authors (Metters, 1996; Cachon, 1999).

In summary, the bullwhip effect phenomenon has been described in the literature over many years; however, it is only in the past decade that the full extent of the problem has been recognized, which has stimulated the interest of a number of researchers. It is noticeable that better information sharing between the members in a supply chain may help mitigate the damages of bullwhip effect. The advances in information technology may offer some assistance to this matter. Some future research may investigate the impact of bullwhip effect in the information age and define new models to alleviate deficiency caused by this phenomenon.

MODELS ON OPERATIONAL RELATIONSHIPS:

Operational relationships in SCM are widely researched and they mainly cover the models in pricing, inventory, and capacity management. The following sections review the literature in these three sub categories.

- PRICING MODELS:

Research in pricing models are mostly related to "timing" for limited capacity product, that is, prices are determined based on the time priorities (the user needs the product now higher priority, or he can wait until the product is available after a delay lower priority), and the prices are set based on the priorities. Several papers study the internal pricing for service facilities (Mendelson and Whang, 1990; and Dewan and Mendelson, 1990), others study the pricing policies in the competing firms in a supply chain (Lederer and Li, 1997). Also others study the pricing for optimal bundling strategies for information goods.

Dewan and Mendelson (1990) study optimal pricing and capacity decisions for a service facility in an environment where users' delay cost is important. Their model assumes a general nonlinear delay cost structure and incorporates the tradeoff between the delay cost and capacity cost. A queuing model is defined by considering a flow of service requests generated by a continuum of atomistic individual users to the system. Each job is set a price by the service department and each user makes individual decision on whether or not to submit his jobs for service. Under certain restrict assumptions, the job arrival and service times are modeled in a queue. Based on the short run and long run situations, the authors develop the optimal pricing scheme that would lead to an optimal utilization of the available capacity.

Also using the queuing theory, Mendelson and Whang (1990) conduct a similar research and derive a pricing mechanism which is optimal and incentive-compatible in the sense that the arrival rates and execution priorities jointly maximize the expected net value of the system while being determined, on a decentralized basis, by individual users. The resulting price structure from their model reveals how the factors of job length and priority each contribute to the overall costs invlicted by a job on the rest of the system.

The queuing theory is also used by the research by Lederer and Li (1997), when they study how delay costs affects prices, operating policies, sales, and firm profits in a competitive environment. This paper assumes that firm capacity, processing variability and cost function are all fixed. The prices are determined by the competitive equilibrium developed in the paper.

One type of the products in a supply chain is the information goods software or other copy righted materials that are distributed online (almost costless via data networks such as Internet) or in stores. The existing traditional theory and practice in SCM are not suitable for providing clear guidance on how digital information goods should be packaged, priced, and sold. Bakos and Brynjolfsson (1999) analyze the strategy of bundling a large number of information goods and selling the bundle for a fixed price. The authors use statistical techniques to provide strong asymptotic results and bounds on profits for b bundles of any arbitrary size. It is shown that the model can be used to analyze the bundling of complements and substitutes, bundling in the presence of budget constraints, and bundling of goods with various types of correlations and how each of these conditions can lead to limits on optimal bundle size.

- INVENTRY MODELS:

Inventory management may be one of the most important fields and takes a major portion of the SCM models researched in the category of operational relationships.

An early paper by Topics (1968) considers the problems associated with an inventory system in which demands for stock are prioritized based on its classes of importance. The author investigates the conditions that will satisfy the optimal rationing policy. A later research by Nahmias and Demmy (1981) continues the study and model an inventory system which maintains stock to meet both high and low priority demands. They analyze the following type of control policy: there is a support level, say $K > 0$, such that when the level of on hand stock reaches K, all low priority demands are backordered while high priority demands continue to be filled. Both continuous review and periodic review systems are considered. They compare fill rates when there is rationing and when there is no rationing for specified values of the reorder point, order quantity and support level.

Along the same line, Axsater (1993) by comparing the one-for-one replenishments at the retailers, studies the exact and approximate evaluation of general installation stock policies where both the retailers and the warehouse order in batches. Similar to most others, the author assumes an inventory system with N identical retailers. Other assumptions are stationary and independent poison demand, significant order costs, and constant lead time, etc. Such strict assumptions make the mode rigorous but the relevance of it to the practices is questionable.

A different inventory system is considered by Ha (1997). The author investigates the inventory rationing in a make to stock production system with several demand classes and lost sales. The simple queuing model and numerical analysis show that the optimal policy can be characterized by a sequence of monotone stock rationing levels. For each demand class, there exists a stock rationing level at or below which it is optimal to start rejecting the demand or this class in anticipating of future arrival of higher priority demands.

Rather than studying the inventory rationing, Cachon and Zipkin (1999) consider two games. In both, the supply chain stages independently choose base stock policies to minimize their costs. The games differ in how the firms track their inventory levels (in one, the fimrs are committed to tracking echelon inventory; in the other they track local inventory). The authors compare the policies chosen under this competitive regime to those selected to minimize total supply chain costs, i.e., the optimal solution. The analysis shows that the games nearly always have a unique Nash equilibrium, and it differs from the optimal solution, which results in that competition reduces efficiency. Furthermore, the tow games' equilibria are different, so the tracking method influences strategic behavior. The authors show that the system optimal solution can be achieved as a Nash equilibrium using simple linear transfer payments.

Also use the game theory, Cachon (2001) continues the research and examines the supply chain inventory game, in which the firms manage inventory with reorder point policies; competition leads to a pure strategy Nash equilibrium in reorder points, which is a set of reorder points such that no player can lower its cost by deviating from the equilibrium, assuming the other players play their equilibrium strategies; there are no profitable unilateral deviations. The model investigates the competitive behavior in the supply chain inventory game and shows that Nash equilibria exist in reorder point policies. The author also suggests cooperation strategies available to the firms to help improve supply chain performance.

- CAPACITY MODELS:

The research of capacity for the supplier in a supply chain are very closely linked to and mostly embedded in the studies of other areas such as inventory and pricing, as well as contracting relationships. Only a few models specialize in discussing the particular topics for this type of relationship as how to find the optimal solutions for choosing and allocating capacity instead of through price mechanisms. The general assumptions for this type of models are that supplier has limited capacity and retailer orders exceed available capacity.

Cachon and Lariviere (1999) discuss the allocation game and find the Bayesian equilibrium to investigate the allocation mechanisms that are manipulable and induce retailers to misrepresent their needs (bullwhip effect) and those that are truth inducing and lead to truthful reporting of retailer information. The authors also discuss the benefits for the retailers from restricting the supply chain to truth-inducing mechanisms. Finally they show how the chosen allocation mechanism influences how much capacity the supplier elects to build. In general, the authors focus is on the impact of the quality of information (truthfulness) and the mechanisms to induce them.

Linear programming models, incorporating the concept of planned lead times with multi-period capacity consumption are used by Spitter et al. (2005) to solve the general capacitated assembly problem. They propose two linear program formulations to find the optimal solution. One is that the capacity restrictions are incorporated using cumulative inequalities. The decision variables involved relate to quantities released at the start of a period and quantities processed in a period. The other one is that the cumulative inequalities are replaced by more detailed equalities. The decision variables involved in this formulation relate to quantities released in a particular period and processed in another (later) period.

SUMMARY OF SCM MODELS RESEARCH:

The models presented above are established on very sound mathematical and logical analysis; however, most of them have strict assumptions. For example, in a two echelon supply, as used in most models, the supplier and retailer are all risk neutral. Theoretically, this is not a problem, but in practice, there are few firms are risk neutral. Another example of restrictions is that demand is stochastic, which may not hold in practice. These questionable assumptions lead to a call for rigorous inter-disciplinary research to establish a framework that apply the theoretically strong models to a practical situation with the consideration of firms' behaviors that may violate some or all of the assumptions in those models one way or the other.

This review of research looks into the models for SCM in the major literature in the management and decision science journals and classifies them into three categories. The sole purpose of the categorization is to provide a clear and precise view of the SCM models literature, based on which we can find the gaps in the current research.

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