# Models for Supply Chain Management: A Taxonomy

Global Supply Chain Management

## *Abstract*

This paper proposes a reasoned taxonomy of the models for supply chain management (SCM). The aim is to help managers select the SCM models most appropriate to their problems and objectives. The taxonomy is based on two dimensions, namely the type of SCM problem and the modeling approach. SCM problems are classified into two main classes, namely configuration and coordination. Four different modeling approaches are considered: conceptual, analytical, artificial intelligence and simulation. The related literature is reviewed according to the proposed taxonomic criteria and areas for further research are identified.

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## *1. Introduction*

A Supply Chain (SC) is a network of organizations that are involved in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer [Christopher, 1992]. Supply Chain Management (SCM) concerns the integrated and process-oriented approach to the design, management, and control of the SC, with the aim of producing value for the customer, by both improving customer service and lowering cost.

Supply Chain Management concerns diverse areas, such as demand forecasting, procurement, manufacturing, distribution, inventory, transportation, and customer service, which are dealt with under strategic, tactical, and operational perspectives. Furthermore, different streams of studies have contributed to the SCM literature, for example Industrial Dynamics (Forrester, 1961; Towill, 1996), Value Theory (Porter, 1985), Network literature (Thorelli, 1986; Jarillo, 1988), Market Channel Theory (Stern and El Ansary, 1992), Business Logistics (Christopher, 1992; Bowersox and Closs, 1996), Strategic Management (Cox, 1997; Dyer *et al*., 1998), and Inter-organizational Behavior (Harland, 1996).

The term SCM is also associated with a variety of meanings. It was originally used in the early 1980s in the logistics literature, to describe a new integrated logistics management approach across different business functions, such as purchasing, manufacturing, distribution, and sales (Houlihan, 1984). Later on, this integrated approach was extended outside a firm boundaries to customers and suppliers (Christopher, 1992; Bowersox and Closs, 1996). Lately, the term SCM tends to be utilized in a wider sense and encompasses several SC processes not necessarily related to logistics. According to the Global Supply Chain Forum (Lambert *et al*., 1998), SCM is the integration of the key business processes from end users through original suppliers that provides products, services, and information that add value for customers and other stakeholders. The key supply chain business processes that should be linked along the SC are: customer relationship management, customer service management, demand management, order fulfillment, manufacturing flow management, procurement, product development and commercialization.

The complexity of SCM due to the multidisciplinary aspects and the variety of meanings has determined two consequences on the academic and practitioner fields. On the one hand, it is



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the reason for the non-acknowledgment of the SCM as a discipline, given that it is unclear what are its boundaries. On the other hand, it has generated a gap between the academic work on SCM and practical implementations. In fact, despite the great number of models that have been developed to address SCM problems, the great majority of them has yet to be put into practice.

Therefore, more emphasis should be placed to define SCM, in terms of areas and meanings. Then, the available models can be classified in order to clarify the utilized techniques and the specific application contexts. In this paper we propose a classification of the main SCM problems. In particular, we focus on the stream of studies related to Operations Management.

The key objective is to review the SCM literature in order to develop a taxonomy of SCM models. The taxonomy intends to support managers in selecting SCM models appropriate to their problems. The taxonomy is based on two dimensions, namely the problem type and the modeling approach. SCM problems are grouped into two broad classes, i.e. SC configuration and SC coordination. With respect to the modeling approach, four classes are identified: conceptual, analytical, artificial intelligence, and simulation models.

The paper is organized as follows. In Section 2 the classification of SCM problems is proposed. In Section 3, SCM models are reviewed and classified based on the type of SCM problem and the modeling approach, namely conceptual, analytical, artificial intelligence and simulation. In Section 4 the literature review is focused on the last three years so as to identify the most recent trend in studies on SCM and highlight needs and opportunities for further research.

## *2. SCM Problems*

In the last years several studies have addressed the issue of developing SCM frameworks aimed at classifying the wide related literature. Cooper *et al*. (1997) develop a framework that is based on (i) the SC structure, (ii) the SC business processes, and (iii) the SCM components. Betchel and Jayaram (1997) identify the different school of thoughts in the SCM literature and propose a model for its analysis. In particular, such a model distinguishes between content and process-oriented literature. Croom *et al*. (2000) analyze the different bodies of knowledge that are associated with SCM and present a taxonomy of the literature aimed at identifying the key SCM content. Also, they describe and evaluate the main utilized methodologies.

This paper is focused on the Operations Management area, which is split into three main application contexts, namely customer management, production management, and product development. Customer management concerns the activities related to identify the key target market and implement programs with key customers. Production management includes different processes such as procurement, forecasting, order fulfillment, and logistics. Product development, when dealt with according to SCM, involves strategies such as the design for SCM (Lee, 1993) and the design for localization (Lee and Billington, 1995).

The proposed review is focused on the Production Management context, so as to identify the SCM problems that are specific to this context. This would in particular be useful to a focal company, as it is likely to be the one driving the SC towards the implementation of SCM practices.

We distinguish to broad types of SCM problems in the production management context: (i) SC configuration, and (ii) SC coordination.

Configuration mainly involves problems at a strategic level dealing with the design of the supply chain network, in particular supply, production, and distribution networks (left column in Table 1).

Relevant decisions in the design of the supply network concern the make or buy problem, the supply strategy, the sourcing policies, and the supplier selection process.

Notice that under a SCM perspective, a focal company should consider not only the first tier suppliers but also the subsequent tiers (upstream in the chain). Furthermore, companies should recognize the importance of infrastructure suppliers as they often contribute as (or even more than) product suppliers to create value to the customer (Fine and Whitney, 1999). Therefore, the infrastructure SC as well should be appropriately designed and managed.

The design of the production-distribution network mainly involves the location-allocation problems. The latter occur whenever the location of several facilities (such as plants and warehouses) is to be determined, simultaneously along with the allocation of flows between the facilities, to serve a set of demand centers. Other issues to be addressed include outsourcing decisions, the type of distribution channel (e.g. number of echelons, number of location per echelon), and environmental aspects, in particular the need for a recycling network.

To sum up, solving a configuration problem means to determine nodes of the SC and related linkages as well as identify the actors that operate them.

Coordination problems concern the management of the supply chain network prevalently under tactical and operating perspectives.

Different types of coordination have been identified in the operations management literature. Ballou *et al*. (2000) identify intra functional, inter functional, and inter-organizational coordination. Bhatnagar *et al*. (1993) distinguish between multi plant and general coordination. Whang (1995) emphasizes also the organizational perspective, under which he distinguishes three alternatives to pursue coordination, namely the single person, the team, and the nexus of contracts.

Hence, the coordination problems in a SC are quite complex given that they arise from the need of integrating operational decisions that are generally made by several different actors (decision-makers). Such decisions, which can concern a single function or different functions and involve more that one organization, should be coherently guided so as to increase the total SC performance (channel coordination).

Furthermore, in the selection of a SCM model appropriate to a given problem, beside the quite obvious importance related to whether the coordination is intra functional, inter-functional, or inter organizational, a key issue is to realize whether the decision making process will occur in a centralized or decentralized fashion. This indeed involves two different types of coordination problem.

A centralized decision making process is associated with a unique decision maker in the SC who should possess all the information on the whole SC that is relevant to make decision as well as the contractual power to have such decisions be implemented.

When the decision making process is decentralized, several decision-makers exist in the SC who generally possess information on only a part of the SC (local information), pursue different objectives (local objectives), possibly conflicting among each other. In fact a behavior that is locally optimum is likely to be globally sub-optimum [Whang, 1995]. Coordination mechanisms are then necessary so as to have local decision-makers pursue the channel coordination. In fact, such mechanisms utilize incentives to make SC actors' decisions coherent among each other. In particular, the incentives let the risk and the revenue

(which arise from different sources of uncertainty and from channel coordination, respectively) be shared by all SC actors.
Therefore, we classify SC coordination problems on the basis of which operational decisions are jointly coordinated. Operational decisions can concern two functions (marketing-production, production-distribution, inventory-distribution, distribution-recycling, etc.) or more than two functions.
At the same time SC coordination problems need to be distinguished according to the adopted decision making process. In fact, even though the latter can be considered also as a model feature, it depends on the organizational aspects that characterize the given SC and, hence, on the considered SCM problem. As discussed above we distinguish two types of decision making process, namely centralized and decentralized. As a result, the proposed classification of SC coordination problems (right column in Table 1) holds for both types of decision making process.

*See Table 1*

# *3. Models for SCM*

In this Section a taxonomy of the models for SCM is proposed, which is based on two dimensions, namely the type of SCM problem (i.e. SC configuration and SC coordination) and the modeling approach. In particular, we identify four classes of modeling approaches: (i) conceptual, (ii) analytical, (iii) artificial intelligence, and (iv) simulation.
The reviewed models have been selected as related to SCM, based on whether they address one or more SCM problems as identified in Table 1. Even though the proposed literature review is not intended to (and could hardly) be exhaustive, it identifies a great number of important models and allows such models to be easily chosen according to the proposed classification criteria.

## *3.1. Conceptual Models*

Conceptual models consist in descriptive tools, which outline the main aspects and the relevant variables involved in a specific SCM problem, and/or prescriptive frameworks, which propose guidelines, generally empirically based, for addressing specific SCM problems.

*Configuration*

The great majority of conceptual models address the SC configuration problems. With regard to the supply network design, many models concern the make or buy decision, the supply strategy, and the supplier evaluation process.
Kraljic (1993) underlines the strategic importance of purchasing to achieve competitive advantage. Fine and Whitney (1999) argue that the make or buy decision is a core competence for a company.
Cànez *et al*. (2000) propose a literature review of the make or buy approaches and develop a theoretical framework to address the make or buy decision. In particular, the framework identifies the decision triggers and important factors that influence the decision process. The latter are grouped into four main areas, namely technology and manufacturing process, cost, supply chain management and logistics, and support systems.
A general trend characterizing supply relationships in SCM is the shift from an *arm's length* to a *partnership* approach (Ellram, 1991; Lamming, 1993). Spekman *et al*. (1998) describe

the advantages of a close collaboration between buyer and supplier along the entire SC. Strategic partners share risks and benefits, exchange operating and financial information, make joint investments in facilities and systems, are jointly involved in continuous improvement and new product development programs, and make their success interdependent.

Several portfolio approaches for the supply strategy have been developed. Olsen and Ellram (1997) define four classes of supplier relationships on the basis of the management complexity and strategic aspects related to the supplied product. The former is influenced by the characteristics of the product, the supply market, and the environment. The latter depends on the required capabilities, the production volume, and the supplier reputation. Dyer *et al*. (1998) propose a model of supplier segmentation between durable arm's length relationships and strategic partnerships, so as to optimize the allocation of scarce resources. This decision is based on the extent to which the supplier provides high value inputs and plays an important role in differentiating the buyer's final product. Bensaou (1999) identifies two steps for implementing a portfolio approach: first, a contextual profile of any buyer-supplier relationships has to be defined based on the product, market, and supplier characteristics; second, a management profile has to be associated with each relationship (i.e. contextual profile) type. He characterizes four management profiles (associated with as many contextual profiles) in terms of information sharing mechanisms, boundary spanners' job characteristics, and climate and process characteristics.

As a higher level of cooperation in the buyer-supplier relationships requires a larger number of criteria for the supplier selection process, many scholars have developed models to address this problem. Weber *et al*. (1991) propose different supplier selection criteria based on price or cost, quality, and delivery. Ellram (1990) considers four categories of supplier selection criteria: (i) financial issues, (ii) organizational culture and strategy, (iii) technology, and (iv) a group of other factors. McCutcheon and Stuart (2000) propose a model of the two sets of factors that need to be considered in selecting partners for a supplier alliance. The first set describes the nature of the supplier and of the input he/she provides. The second set measures the level of trust that exists between supplier and buyer. Giannoccaro and Pontrandolfo (1999) focus on the difference between product supplier and infrastructure supplier selection criteria.

Scott and Westbrook (1991) propose two tools to respectively assess the SC status in terms of the SC global responsiveness to the customer and the level of collaboration with suppliers. The former is described through the pipeline map, which depicts by horizontal lines the time spent in each production process and by vertical lines the time in inventory at the stocking points. The latter is dealt with the supplier relationship grid, which positions the companies on a matrix based on the type of supplier relationship and the number of suppliers to the major end customer.

Hines and Rich (1997) describe seven tools to map inter-company and intra-company value adding processes along the SC, namely process activity mapping, supply chain response matrix, production variety funnel, quality filter mapping, demand amplification mapping, decision point analysis, and physical structure. Such tools are aimed at removing different types of waste that are associated with overproduction, waiting, transport, inappropriate processing, unnecessary inventory, unnecessary motion, defects, and the overall SC structure.

The outsourcing decision on the distribution side mainly addresses the question whether to use outside contractors or in house distributor. Aertsen (1993) develops a theoretical model based on the transaction cost theory. He claims that outsourcing decision mainly depends on two factors, namely the degree of asset specificity and the ease of performance

measurements. In particular, he shows that asset specificity and difficult performance measurements leads to an own-account distribution function.
Skjoett-Larsen (2000) develops a theoretical framework based on transaction cost theory and network theory, useful to study the third party logistics arrangements. In particular, he shows that third party logistics not only improve cost efficiency but is also a source of strategic advantage, in terms of improved service level and flexibility.
An important issue in the design of distribution network is the recovery problem. Fleischmann *et al*. (2000) study the design of a logistic network for product recovery activities. In particular, they identify three product recovery network classes, namely recycling, remanufacturing, and reusable item networks.

*Coordination*

Conceptual models for SC coordination generally concern the SC configuration as well. However, their final objective is the achievement of a process oriented approach in the management of the SC, which is why we have classified them into the coordination category.
Such models mostly consist in theoretical frameworks, which help address the coordination problem with the implicit assumption that the SC control is centralized.
Steven (1989) describes model for identifying the steps needed to attain a totally integrated supply chain, from a functional point of view. The model involves four steps: (i) base line, (ii) functional integration, (iii) internal integration, and (iv) external integration. Functional integration concerns the integration of purchasing, material control, production, sales, and distribution, into three independent areas, namely material management, manufacturing management, and distribution. Internal integration consists in the successive tactical integration of these three areas. Finally, external integration is achieved by extending the scope of integrated management outside a firm’s boundaries to embrace suppliers and customers.
Similarly, the Supply Chain Operations Reference (SCOR) model is aimed at supporting managers in the process of SC integration (Stewart, 1997). Four levels are identified in the implementation of SCM. At level 1 the key processes in the supply chain are defined, which can be grouped into plan, source, make, and deliver. At level 2 the core process categories are defined, by which selection a company actually chooses the configuration of its own supply chain. Level 3 includes process element definitions, information, benchmarks, best practices, needed capabilities, and available commercial tools. Level 4 corresponds to the implementation stage of the identified managerial practices.
Evans *et al*. (1995) describe a Business Process Re-engineering (BPR) based approach to supply chain integration. They also emphasize the complementary aspects of BPR and SCM philosophies.
An exception to the centralized control assumption is given by (Nishiguchi and Beaudet, 1999), who describe a coordination model for a decentralized SCM, named fractal link design. The latter has been adopted by Toyota and is based on knowledge transfer mechanisms to create similar capabilities in the supply base. This approach is innovative in that first-tier suppliers utilize it in the relationships with their suppliers, with no need of control by Toyota.

### *3.2. Analytical Models*

Analytical models for SCM problems are based on different Operations Research techniques, mainly linear programming, dynamic programming, mixed integer programming, multi objective programming, markov decision process, and analytical hierarchy process.
They address configuration as well as coordination problems.

*Configuration*

Analytical models that address SC configuration problems mainly concern the supplier selection process and the design of production-distribution network.
The supplier selection and evaluation models are mainly based on the following techniques: linear weighting (Ellram, 1990; Fawcett, 1993), linear programming (Tagaras and Lee, 1996; Roodhooft and Konings, 1997; Weber and Current, 1993), mixed integer programming (Sadrian and Yoon, 1994; Chaundhry *et al*., 1993), multi-objective programming (Weber and Current, 1993; Nam *et al*., 1995), and analytic hierarchy process (Nydick and Hill, 1992; Masella and Rangone, 2000). A key feature of these models is the use of a multi criteria approach for the decision making process.
Recently, Li and O'Brien (1999) have developed a model based on two hierarchical levels. The first level can be associated with a central decision maker (at the chain level) that weights the objectives based on four criteria, selectively per SC stage, and solves a typical multistage dynamic decision problem for selecting the best suppliers. At the second (operational) level, each single organization optimizes the operational costs under the assigned objectives.
With regard to the design of production-distribution network, the majority of models deal with the location-allocation problem adopting the mixed integer programming (MIP) technique (Geoffrion and Graves, 1974; Geoffrion *et al*., 1978; Brown *et al*., 1987; Cohen *et al*., 1989; Cohen and Lee, 1989; Cohen and Moon, 1991; Pirkul and Jayaraman, 1998).
In particular, Pirkul and Jayaraman (1998) develop a mixed integer programming model (PLANAR) for addressing multi commodity, multi plant, capacitated facility location problem. The problem consists in selecting the optimal set of plants and warehouses and planning production and warehouse capacity so as to minimize the total operating costs. They propose a heuristic procedure, based on Lagrangian relaxation, to solve this model.
Some case studies are also available, which develop models for addressing real SC cases. For example Lootzma (1994), Arntzen *et al*. (1995), and Camm *et al*. (1997) utilize MIP for solving SCM problems at Philips Electronics Industries, Digital Equipment Corporation, and Procter and Gamble Company, respectively.
De la Fuente and Lozano (1999) propose a model, based on cluster analysis, to decide the optimal number of warehouses and the attendant location within a region of Spain.
Goldsby and Closs (2000) describe an application of Activity-Based Costing to re-design the reverse logistics across a supply chain. This model involves two steps. First, it determines the cost centers for each SC actor and maps the firm activities. Second, it attaches cost quotas to the reverse logistics activities and then, such costs are attributed to specific products, customers or channels. This model is claimed to be a tool to better design the SC.

*Coordination*

As mentioned above, coordination problems can be distinguished between centralized or decentralized, according to the adopted decision making process. Such a difference is reflected in the reviewed analytical models. Therefore, we discuss first the centralized, then the decentralized case.

*Centralized decision making*

Marketing-production coordination includes the issues of jointly addressing pricing decisions with inventory or production planning as well as synchronizing customer delivery with production planning.

For example, Gilbert (2000) studies the relationship between the selling price and the production plan. He considers a seasonal and price dependent demand and demonstrates that, given products experiencing demand peaks in the busy season, those products that peak early should be more aggressively priced.

Weng (1999a) studies the problem of delivering customized orders quickly while maximizing the expected profit. He develops a model to jointly optimize the manufacturing lead-time and the order acceptance rate. In particular, the trade-offs and the interrelationships among manufacturing flow times, lead-time reliability (low earliness and tardiness), demand rates, inventory levels, resource utilization, and expected profits are analyzed.

Weng (1999b) considers a two-stage supply chain, i.e. manufacturing and distribution, which faces a price-sensitive random demand and is characterized by a short product life cycle. He determines the optimal coordinated pricing and production/ordering decisions.

Supply production coordination mainly concerns the determination of the order quantity that is optimal for both the buyer and the vendor. Most of these models deal with SC made up of one buyer and one supplier. Models in which the buyer has alternative suppliers are less common.

Monahan (1984) proposes a quantity discount mechanism in which the buyer receives a purchase price discount in return of an increase of the buyer quantity.

Rosenblatt and Lee (1985) consider also the lot sizing problem of the vendor and show that the optimal order quantity for the vendor will be an integer multiple of the buyer's order quantity. They propose a linear discount schedule.

Banerjee (1986) develops the joint optimal lot size model for a single buyer-single vendor system where the vendor has finite capacity.

In the above models demand is deterministic and operating costs depend on the order quantities. Jeuland and Shugan (1983) address the same problem (jointly optimization of the buyer and supplier profits), being demand a decreasing function of the buyer's selling price and operating costs a fixed constant.

Production-distribution coordination concern the jointly optimization of production and distribution problems. Several models determine the optimal production and distribution batch sizes (Williams, 1981; Haq *et al.*, 1991, Chien, 1993); others focus on the determination of inventory control parameters, such as the reorder interval, the replenishment batch size, and the order-up-to level (Pyke and Cohen, 1993; 1994); in other cases, the determination of base stock levels and production lead-times is addressed (Ishii *et al*. 1988).

Weng (1999c) analyzes the value of three types of production-distribution coordination strategies, namely concurrence, postponement, and trans-shipment, in terms of the amount of safety stock that is necessary at the distribution centers (DC) to satisfy an assigned service level. He considers a two-echelon SC with one manufacturing center and n DCs. The manufacturing center produces a variety of products according to a cyclical production policy. Decisions to allocate product to the DCs are deferred at the end of the manufacturing lead-time.

Inventory-distribution coordination models address the inventory management problem in production-distribution systems. The objective is to determine the inventory policy that is optimal for the whole system. These models, which are known as multi-echelon inventory management models, can be grouped into two classes, based on the system structure, namely serial or arborescent.

In their seminal work on multi echelon inventory management, Clark and Scarf (1960) consider a serial SC and show that echelon base-stock policies are optimal in a periodic-review, finite-horizon setting. Multi echelon inventory problems in arborescent systems, which are known as 'one warehouse-multi retailers', have been analyzed by Federgruen and Zipkin (1984), Anily and Federgruen (1990), and Chandra (1990).

The great majority of multi echelon inventory models generally consider two-echelon SCs, whereas rarely three-echelon SCs are studied due to the higher computational complexity. Ganeshan (1999) considers a three-stage SC with a multiple suppliers replenishing a central warehouse, which in turn distributes to a large numbers of retailers. He determines a reorder point, order quantity policy for the retailers and warehouse, which minimizes the logistics costs under customer service constraints.

A growing attention has recently been devoted in the multi echelon inventory management literature to the demand variability effect, known as Bullwhip effect. Kelle and Milne (1999) model a multi echelon inventory distribution system and develop a quantitative tool to assess the effect of ordering inventory policy, demand parameters, and logistics costs on the demand variability.

Graves *et al*. (1998) focus on the inventory-production interface. In particular, they develop a model of dynamic requirements planning in a supply chain, whose basic module is a single stage production inventory model, which optimizes the trade-off between production smoothing and low inventory holding. The model takes as input the demand requirement and gives as output the production plan. The production plan is then the input to the upstream stage.

Attention to the coordination of distribution and recycling is given by Albino *et al*. (1999), who propose an input-output process model approach for modeling material/energy flows within SCs.

Richter and Sombrutzki (2000) develop a reverse (product recovery) version of the Wagner/Whitin's dynamic production planning and inventory control model. Their algorithm determines the optimal production planning for both regular products and to be re-worked used products, which have to be remanufactured at minimum cost.

A few studies address the issue of coordination of more than two functions. Blumenfeld *et al*. (1985) propose a model that analyzes the integration of production, inventory, and transportation functions. Jørgensen *et al*. (1999) present a model to define the optimal production, inventory, and pricing policy of a monopolistic firm over a fixed and finite horizon. The model is built upon three different fields of studies, namely operational research, marketing science, and industrial organization. Escudero *et al*. (1999) develop an approach to solve a multi period, multi product, multi level manufacturing, assembly, and distribution planning problem (MAD) under uncertainty.

*Decentralized decision making*

Among the SCM models that adopt a decentralized decision making process, we focus on SC contracts, which include the quantity discounts, the quantity flexibility, the backup agreements, the buy back or return policies, the incentive mechanisms, and the revenue sharing contracts.

Lau and Lau (1999) develop a model that address marketing-production coordination based on return policies. According to this contract, the manufacturer decides the wholesale price C and the unit credit *V* to be given to the retailer per unit returned. The retailer decides the order quantity. They show that depending on the risk attitudes of the manufacturer and the retailer, the optimal return policy can range from ‘no returns allowed’ to ‘unlimited returns with full credit’.

With regard to supply-production coordination, the quantity discount is a coordination mechanism that allows a joint optimal order quantity for buyer and vendor to be found. In fact, under this mechanism, the supplier induces the buyer to order the global optimal quantity, by offering to her a price discount. Different types of discount mechanisms exist, i.e. all-unit and incremental (see Dolan (1987) for a review).

Weng (1995) considers a SC with one buyer and one supplier. Demand is a decreasing function of the buyer’s selling price (as often assumed in the marketing literature) and the operating costs depend on the order quantity. In this setting, he shows that quantity discounts does not guarantee the joint profit maximization. Channel coordination needs the simultaneous use of quantity discounts and franchise fees. They respectively assure the minimization of the joint operations costs and the joint profit maximization. Weng (1999d) includes in the model the risk attitude of the SC actors. The more they are risk adverse, the less they benefit from coordination.

Li and Kouvelis (1999) analyze different types of SC contracts, which are based on quantity and time flexibility. In time inflexible contracts, the buyer order must specify the quantity and delivery time. In time flexible contracts, the buyer does not need to specify the delivery time. In quantity flexible contracts the order quantity can be vary in a given range. The authors develop a model in which demand is deterministic and price uncertain. Moreover, they incorporate a risk-sharing feature related to the price uncertainty, in which the purchase price is a function of customer price.

Production-distribution coordination under a decentralized decision making is pursued through different SC contracts, (i.e. quantity flexibility, backup agreements, return policies and revenue sharing contracts) aimed at achieving channel coordination and risk sharing among the SC actors.

Quantity flexibility (QF) models are coordination mechanisms that divide the costs of demand uncertainty among the SC actors. In such models the retailers commit to purchase no less than a certain percentage $\alpha$ below the forecast and the manufacturer guarantees to deliver up to a certain percentage $\omega$ above the forecast. The QF relationship between the manufacturer and the retailer can be described by the following parameters $\{c, (\alpha,\omega)\}$, $c$ being the transfer price.

Tsay (1999) models the inefficient behavior that occurs in decentralized SCs and shows that this problem can be at least partially dealt with by QF contracts. In fact, the QF contract itself does not guarantee efficiency, but appropriate values of $c$ allow the SC profits to be shared by the manufacturer and the retailer so as to achieve efficiency.

Tsay and Lovejoy (1999) extend the QF contract in a multi-echelon SC with a rolling production planning horizon. They study the impact of QF on inventory characteristics and show that QF contracts reduce the bullwhip effect in the SC. They also study the design of QF contracts, in particular by analyzing the buyer’s “willingness to pay” for flexibility.

Backup agreements are contracts between a catalog company and manufacturers, which are similar to quantity flexibility contracts. Under a backup agreement, the catalog company commits to purchase $y$ units before the selling season, and the manufacturer holds a fraction $\rho$ of the commitment and delivers the remaining. After observing demand, the catalog company can order up to the backup quantity at the same purchase price, but has to pay a penalty cost $b$ for any unit of the backup that it does not buy. Backup agreements intend to help catalog company reduce the impact of uncertainty about demand.

Eppen and Iyer (1997) develop a stochastic dynamic programming model of backup agreements. In particular, they study the impact of contract parameters ($b$, $\rho$) on the expected catalog company's profit. An increase in the value of $b$ is accompanied by a lower advantage of using a backup agreement, whereas the vice versa occurs for an increase of $\rho$. The latter effect is reduced by an increase of $b$. They also develop an expression to measure the impact of backup agreements on the manufacturer's profit and show that for certain values of ($b$, $\rho$) both the catalog company and manufacturer profits improve.
Under return policies, the retailer may return unsold units to the manufacturer. Such a contract type is suggested for SCs wherein retailers sell styled goods to customers by catalogue, manufacturers have long production lead-time, and selling seasons are short. The decisions that pertain to the retailer are the order quantity and the customer price. The manufacturer decides on the wholesale price and the repurchase price of unsold units.
Emmons and Gilbert (1998) study the effect of return policies on both manufacturer and retailer profits. Such policies are aimed at maximizing the manufacturer profit, by inducing the retailers to place larger orders. Demand is uncertain and price dependent. In this model, the manufacturer makes decision taking into account the self-interested behavior of the retailers. In particular, the authors show that the manufacturers can increase their profits by offering to repurchase the unsold products of the retailers. Moreover, they show that for given wholesale price, both the manufacturer and retailer profits tend to increase, so obtaining a win-win situation.
Iyer and Bergen (1997) study the impact of a Quick Response (QR) strategy on a manufacturer-retailer chain. They show that QR may be not profitable for the manufacturer and propose three mechanisms (service level, wholesale price, and volume commitments) to make QR advantageous for all the members of the supply chain.
Cachon and Lariviere (2000) propose the revenue sharing contract and study the impact on SC performance. The contract can be described by the two parameters ($\omega$, $\Phi$): the supplier charges a per unit wholesale price $\omega$, lower than the unit marginal cost $c$, in exchange for a percentage $\Phi$ of the retailer's profit. The position $\omega < c$ guarantees channel coordination whereas $\Phi$ determines the distribution of total profits between buyer and retailer. In particular, $\Phi$ is the SC profit quota gained by the retailer. The authors also demonstrate that revenue sharing contracts can coordinate systems with multiple competing retailers.
The coordination of inventory-distribution includes the decentralized multi-echelon inventory management models. Lee and Whang (1999) develop a coordination mechanism model for a decentralized serial SC, which generalizes the model by Clark and Scarf (1960). They propose a performance scheme for aligning SC actors incentives, based on four mechanisms, namely transfer price, consignment, additional backlog penalty at the last downstream site, and shortage reimbursement. They also demonstrate that such mechanisms satisfy the cost conservation, the incentive compatibility, and the informational decentralizability properties.
Cachon and Zipkin (1999) study a two-stage serial SC with stationary stochastic demand and fixed lead-time under a cooperative and competitive behavior. They model the SC inventory problem as a game and show that channel coordination can also be achieved in a competitive situation, by using a simple linear transfer payment scheme.

### *3.3. Artificial Intelligence Models*

Several artificial intelligence techniques have been applied to solve a variety of SCM problems. In general, such techniques are more often utilized for coordination than configuration problems. In the following we focus on expert systems, fuzzy set theory, fuzzy logic, neural network, genetic algorithm, reinforcement learning, and multi-agent systems.

*Configuration*

Artificial intelligence models in SC configuration problems mainly address the supply strategy, the supplier selection process, and the design of production-distribution network.

Cook (1992) reviews the applications of expert systems to purchasing problems. In particular, he stresses the need of developing decision support systems, based on expert systems, to make decisions faster, more accurate, and more consistent.

Tucker and Jones (2000) develop a new class of buyer supplier relationships, which they name Internet-based trading, and identify the benefit gained by the organizations that adopt this strategy. Furthermore, they describe the use of intelligent software agents to optimize the sourcing process over the Internet. They show that this technology as well as the trust in buyer-supplier relationship enables the Internet-based trading.

With regard to the supplier selection process, Albino *et al*. (1998) develop a vendor rating model, which is based on fuzzy logic and is able to process verbal variables. In particular, they use two different approaches. One is based on a fuzzy algorithm and the other is based on a fuzzy neural network. The performance of the two systems is then compared.

Lozano *et al*. (1998) develop a neural network approach, in particular Kohonen Maps, to solve continuous space location-allocation problem, in which demand centers are independently served from a given number of supply centers.

Castillo and Gonzales (1998) address the problem of the distribution network design from an economic point of view. They develop a model based on genetic algorithms, which determines the optimal network features.

Berry et al. (1998) address the issues of the design of networks characterized by a tree structure. They use a genetic algorithm to define the network topology, whereas linear and non-linear programming techniques are utilized for the problem of assigning traffic flow to the network.

*Coordination*

Several studies address coordination problems by adopting artificial intelligence techniques, under the hypothesis of a centralized decision making process.

Balakrishnan *et al*. (1997) give an example of the use of neural networks to integrate marketing and manufacturing functions.

Van Buer *et al*. (1999) address the problem of production-distribution coordination in the newspaper industry. They develop a genetic algorithm and, in particular, show that low-cost solutions can be achieved through the re-use of trucks that have completed earlier routes.

Many are the studies addressing SC inventory management with fuzzy set theory for modeling uncertainty (Kacprzyk and Staniewski, 1982; Katagiri and Ishii, 2000; Petrovich *et al*., 1999; Giannoccaro *et al*., 2000). Fuzzy set theory can indeed reveal extremely useful, more appropriate, and comparatively more reliable to model uncertainty, by taking into account managerial experience and judgements. Fuzzy variables generally describe the costs and market demand.

Mak and Wong (1995) use a genetic algorithm to solve an inventory-production-distribution problem. They determine optimal stocks levels, production quantities, and transportation quantities so as to minimize the total system costs.

Giannoccaro and Pontrandolfo (2000b) develop an approach based on Reinforcement Learning to address in a stochastic environment the inventory management problem in a supply chain with three stages, i.e. supply, production, and distribution. After having modeled the problem as a Markov Decision Process, they determine through a simulation based learning process a global coordination policy that is near optimal under an average reward criterion.

In recent years new software architectures have emerged for managing SCs at the tactical and operational levels by adopting a decentralized control. In our opinion, this is an interesting research area, due to the great number of real SCs characterized by the absence of an actor that is capable of managing the system in a centralized fashion.
Fox *et al*. (2000) view the SC as a system of intelligent (software) agents, each being responsible for one or more activities and interacting with the others in planning and executing according to its responsibilities. An agent is an autonomous, goal oriented software process that operates asynchronously, communicating and coordinating with other agents as needed. It is intelligent and uses artificial intelligent and operational research problem solving methods. The SC activities are decomposed into different agents such as order acquisition agent, logistics agent, transportation agent, scheduling agent, resource agent, and dispatching agent. Agents are involved in a message exchange that allows coordination. The latter is based on conversation plans, conversation rules, and actual conversations. An adaptive behavior of the agent is achieved by modeling the conversation plan as an MDP process. Two SCM applications are presented: the coordination of a team in a virtual enterprise and the analysis of coordination mechanisms to cope with unexpected events that perturb operations of the SC.
Lin and Shaw (1998) propose a multi agent information system (MAIS) approach for the re-engineering of the order fulfillment process (OFP) in a SC. MAIS is made up of four components: agents, tasks, organizations, and information structure. The authors model MAIS through the multi agent modeling tool SWARM (Santa Fe Institute, 1996) and evaluate the performance associated with different strategies to improve the OFP, namely coordinated demand management policy, information sharing, synchronizing material and capacity availability, and dynamic resource allocation.

### *3.4. Simulation Models*

As in other applications, simulation has the advantage of allowing SCM problems to be dealt in a more detailed and, then, realistic fashion. In this sense, simulation models for SCM are utilized for testing solutions to specific problems. Alternatively, general guidelines can be derived by simulating the behavior of a general and quite simplified system. In this second case, results may have implications on both configuration and coordination design parameters. We found indeed that the boundary between the two problem types is often less clear than for other modeling approaches to SCM problems.
This is the case of industrial dynamics, which mainly focuses on the smoothing of material flow so as to improve SC performance. Back in the early ‘60s Forrester (1961) described the demand amplification effect that occurs as moving upstream in the SC. The latter depends on factors such as the supply chain structure (configuration), the time lags involved in accomplishing actions, and the poor decision making concerning information and material flows (coordination).
Wikner *et al*. (1991) stress that the Forrester effect is lowered mainly through interventions on the SC coordination (fine tuning of existing ordering policies, reduction of delays, change

of local decision rules, and a better use of the information flow through the supply chain), but also working on the SC configuration by the removal of the distribution stage.

Towill (1996) describes how industrial dynamics models can support supply chain re-engineering. Enhanced business performance can be achieved through a better use of resources. He investigates the impact on the SC of different operations strategies, such as JIT and vendor integration (Towill, 1991, 1996).

Baskaran (1998) analyzes via simulation a stamping pipeline in an automobile supply chain based on operational data from General Motors. He focuses on supply chain instability and inventory issues and shows the way in which opportunities for continuous improvement in supply chains can be identified and exploited by simulation.

Hammant *et al*. (1999) describe a simulation based decision support system to determine the optimal distribution structure. This model considers the number of DCs, the location of DCs, the sourcing strategy, and the logistics costs (transportation, inventory, and warehousing).

Van der Vorst *et al*. (2000) present a method for modeling the dynamic behavior of food supply chains. The model is based on Petri nets to support decision making and evaluate alternative design by applying discrete-event simulation. Fundamental components of the model are business processes, performance indicators, design variables, and business entities. Design variables regard the configuration level (i.e. implementing a Computer Aided Ordering system, a real time inventory system, EDI with producer) and the operational and control level.

## *4. Trend in current SCM Research*

In this Section we try to assess the effort that researchers have been making during the very late years in the study of the different SCM problems by adopting any of the identified modeling approaches.

In particular, our objective is to identify specific directions that research has been pursuing with regard to (i) the SCM problems as depicted in Table 1 and (ii) the modeling approaches as discussed in Sections 3.1 to 3.4.

To this end, we have focused on the years 1998 to 2000 and reviewed five scientific journals that are among the most important in the operations management area: European Journal of Operational Research (EJOR), IIE Transactions (IIET), International Journal of Physical Distribution and Logistics Management (IJPDLM), International Journal of Production and Operations Management (IJPOM), Management Science (MS).

According to the above discussion, only papers dealing with the production management application context have been considered. A total of 174 papers have been found, which are classified by year, SCM problem, and modeling approach (Table 2).

Five more papers (not reported in Table 2) have also been found in the reviewed sample, which review the literature related to the identified SCM problems. This number (5 over 179) can then be considered as representative of the effort carried out by scholars to rationalize the available body of knowledge on the topic.

*See Table 2*

In total, the adopted modeling approach is in the majority of cases analytical (60,3%), followed by conceptual (33,3%), artificial intelligence (5,2%), and simulation (1,2%) approaches. Over 60% of the selected papers has been published by two of the five considered journals (EJOR, IJPD&LM), almost evenly shared by the two.

During the considered time period, SC configuration problems have been receiving a growing attention, whereas coordination problem do not show a clear trend. In particular, the number of conceptual models considerably increases, whereas the number of analytical, AI and simulation models do not show a definite trend, in particular being low the number of the latter two.
In Table 3, papers are classified regardless the year. Notice that SC coordination problems have been further split into two categories, namely coordination under a centralized or decentralized decision making control (C-Coordination and D-Coordination, respectively).

*See Table* 3

Papers analyze to a similar extent SC configuration and coordination problems (47% and 53% respectively). With specific regard to coordination problems, it emerges that they are largely dealt with under a centralized approach (68%) and through analytical models (83%). In particular, D-Coordination problems have been receiving a very scarce attention with respect to conceptual, artificial intelligence, and simulation approaches. The conceptual modeling approach is the most adopted to deal with configuration problems (56%). Artificial intelligence and simulation techniques are rarely applied regardless the SCM problem (6% in total) and comparatively more often to address configuration problems (64%).
Based on the above, a few suggestions can be derived to guide further research on the discussed SCM problems. In our opinion, research efforts should be increased on D-Coordination problems. For example, it is noteworthy the absence of a conceptual framework as well as the lack of a literature review (none of the five reviews consider D-Coordination) in such an area. Also, it would be helpful a higher availability of artificial intelligence and simulation models, which are currently few with respect to all SCM problems.

## *5. Conclusions and research opportunities*

In this paper SCM models have been reviewed based on two taxonomic criteria, namely the SCM problem and the modeling approach.
Two main directions for further research have been identified. First, we believe that a higher attention should be devoted to the adoption of artificial intelligence and simulation approaches to address SCM problems.
Second, we believe that there is a need and the opportunity to develop research on coordination problem through approaches adopting a decentralized decision making process. This would indeed be coherent with the great number of real supply chains characterized by the absence of a unique actor that is capable of managing the system in a centralized fashion. The development of SCM models for decentralized coordination could then sensibly promote the diffusion of SCM in practice.

## *6. References*

Available on request.

Table 1. The SCM problems.

| *Configuration* | *Coordination* |
|---|---|
| Supply network | Operational decisions |
| ▪ Make or Buy | ▪ Marketing-Production |
| ▪ Supply strategy | ▪ Supply-Production |
| ▪ Sourcing policy | ▪ Production-Distribution |
| ▪ Supplier selection and evaluation | ▪ Inventory-Production |
| | ▪ Inventory-Distribution |
| Production/Distribution network | ▪ Production-Recycling |
| ▪ Outsourcing | ▪ More than two functions |
| ▪ Location-allocation problem | |
| ▪ Distribution channel design | |
| ▪ Recovery network | |

Table 2. Numbers of papers by year, SCM problem, and modeling approach.

| Problem | Configuration | | | | | | | | | | | | Coordination | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 1998 | | | | 1999 | | | | 2000 | | | | 1998 | | | | 1999 | | | | 2000 | | | |
| Appr. | C | A | I | S | C | A | I | S | C | A | I | S | C | A | I | S | C | A | I | S | C | A | I | S |
| *MS* | - | 2 | - | - | - | - | - | - | 1 | - | - | - | - | 5 | - | - | - | 14 | - | - | - | 9 | - | - |
| *EJOR* | 3 | 2 | 2 | - | - | 2 | - | - | - | 9 | 1 | - | - | 10 | 1 | - | - | 12 | 1 | 1 | - | 9 | - | - |
| *IJPOM* | 2 | 1 | - | - | 4 | - | - | - | 8 | 2 | - | - | - | 1 | - | - | 1 | 2 | - | - | 1 | - | - | - |
| *IJPDLM* | 6 | 1 | 1 | - | 10 | 3 | - | 1 | 12 | 3 | 2 | - | 1 | 1 | - | - | 2 | - | - | - | 7 | - | - | - |
| *IIET* | - | 1 | - | - | - | 2 | - | - | - | 1 | - | - | - | 3 | - | - | - | 6 | - | - | - | 4 | 1 | - |
| **Total** | 11 | 7 | 3 | - | 14 | 7 | - | 1 | 21 | 15 | 3 | | 1 | 20 | 1 | | 3 | 34 | 1 | 1 | 8 | 22 | 1 | - |

Modeling approach key: C = conceptual, A = analytical, I = artificial intelligence, S = simulation

Table 3. Numbers of papers by SCM problem and modeling approach.

| **SCM problem** / **Modeling approach** | **C** | **A** | **I** | **S** |
|---|---|---|---|---|
| D-Coordination | 0 | 28 | 1 | 0 |
| C- Coordination | 12 | 48 | 2 | 1 |
| Configuration | 46 | 29 | 6 | 1 |
| **Total** | **58** | **105** | **9** | **2** |