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SUPPLY CHAIN: CRISP AND FUZZY ASPECTS

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This survey presents crisp and fuzzy models developed for the Supply Chain (SC). To this end, fuzzy concepts are first briefly reviewed. Then the structure of a supply chain system is explained. Recent challenges and ideas on these systems are also surveyed. Then, with reference to different aspects of an SC system, we classify the recent fuzzy models developed for different SC systems and compare them with related crisp models. Applications of the SC in manufacturing and service industries are investigated in each case.

Keywords: supply chain, crisp and fuzzy systems, SC system, material flow, information flow, supplier-buyer relationships

1. Introduction

Recently, the global market schemes have generated new concepts and mechanisms in various economic and industrial sectors. In the complicated global market place, “Core Competencies” of each enterprise empower their competitive advantage(s). Thus, the focus of various organizations is directed to their core competencies. For this reason, they try to manage their internal and external resources comprehensively. This orientation to integrating different parts of a business or a production process causes each industry to move initially toward Computer Integrated Manufacturing (CIM). Thereafter, they have evolved into Computer Integrated Business (CIB). More recently, they have grown into Extended Enterprise (Browne *et al.*, 1996).

As a result, modern managers are engaged more and more in the processes of Decision Making (DM) and are forced to consider all factors within the walls of their factories, as well as external factors with a holistic perspective. This led to Supply Chain (SC) systems or more generally, Value Chain (VC) and Value Stream (VS) approaches (Porter, 1980). SC, VC and VS concepts and definitions, as a total system, have been investigated by many researchers at universities and academic centers, as well as by professionals in industries (Gattorna and Walters, 1996; Handfield and Nichols, 1999; Monczka *et al.*, 1998).

The first concern of a supply chain and a value chain is generally the purchasing process. In such cases, the focus is on the supplier selection, supplier evaluation, relational activities with sellers, and the like (Cavinato, 1992; Ellram, 1991a; 1991b). In a larger perspective, upstream suppliers are considered as a part of a manufacturing/buyer enterprise. Buyers usually plan and control their systems and link them to their suppliers. Tiers or levels of suppliers form a supply network, with the buyer managing and leading it in an integrated way (Dobler and Burt, 1996). Finally, supply chain management leads to a value chain approach, in which all the affecting elements related to the customer(s) are considered and analyzed in a broader view. In this approach, manufacturers and distributors are included in the chain (Davis, 1993; Lee and Billington, 1992). In general, a supply chain is defined as follows (Mabert and Venkataramanan, 1998):

> “A supply chain is the network of facilities and activities that performs the functions of product development, procurement of material from vendors, the movement of materials between facilities, the manufacturing products, the distribution of finished goods to customers, and after-market support for sustainment.”

Based on this definition, such a network in a system contains a high degree of imprecision. This is mainly due to its real-world character and its imprecise interfaces among its factors, where uncertainties in activities from raw material procurement to the end user make the SC imprecise. Thus, it is summarized that fuzzy set theory is a suitable tool to come up with such a complicated system.

This survey presents various approaches to SCM with crisp and fuzzy methodologies. In this regard, different aspects and characteristics of a supply chain are first discussed. Then the main concepts of fuzzy system modeling are explained. Accordingly, we will survey the recent research on crisp and fuzzy SC systems and their real-world applications. Finally, a comparison of these approaches will be presented.

2. Main Aspects and Characteristics of the SC

SC systems can be studied and analyzed from several viewpoints. Yet there are three major perspectives of SC systems: (a) "Material Flow", (b) "Information Flow", and (c) "Buyer-Seller Relations" (see Fig. 1). Apart from these three aspects of SC systems, there are some other building blocks for these systems, such as raw material suppliers, manufacturers of parts, assemblers, Original Equipment Manufacturers (OEMs), distributors, retailers, customers, etc. It should be noted that these aspects examine the SC and all its components in an integrated way.

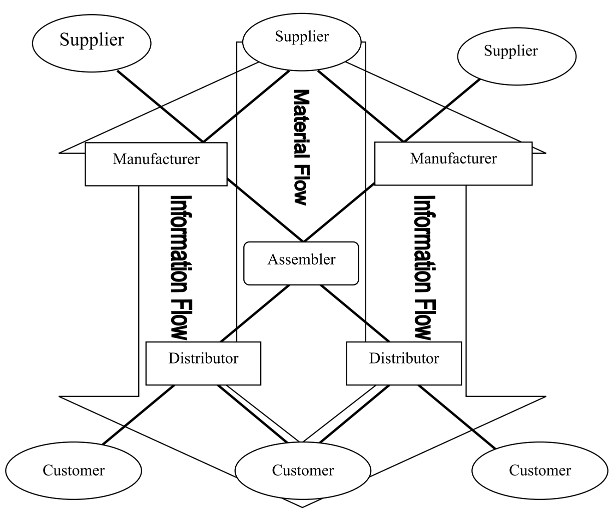

Fig. 1. Material flow, information flow, and buyer-seller relations in an SC.

2.1. Material Flow

Manufacturers should manage their supply resources to meet customer needs. As a matter of fact, today an integrated management of the material flow through different levels of suppliers and distributors is challenging for managers.

Production planning in different sections of a manufacturing enterprise and planning its upstream and downstream activities in a harmonized way are two of the main tasks of managing the flow of materials in an SC. Synchronizing production planning of each entity and, in a more detailed way, scheduling production lines or job shops in these components of the SC are very complicated and often intractable. This complication can be highlighted if we investigate this chain from a product-oriented point of view. Consider a product structure or a tree. In the real world, each level of the product tree is assigned to a supplier. A production plan for such a product which uses, e.g., the MRP approach, determines a due date for each level and each component. When all of these components are produced in one factory, the problem is easier to solve. However, when these levels expand through a chain of suppliers, synchronizing them is usually very complicated, while this synchronization is an obligation in Customer-Driven Manufacturing (CDM).

Clearly, a successful plan critically needs supportive logistics. Transportation planning, inventory management and quality assurance activities are some logistics in the smoothing flow of materials through the SC. These logistic activities should be managed in an integrated way.

2.2. Information Flow

The managing and control of each system comprise several parts. In an SC system, information management is an essential sector. Complexities in business planning activities occur in four areas: (a) technological revolution, (b) product changes, (c) research and development, and (d) information explosion (Murdick *et al.*, 1990). The SC system could be seen as a business enterprise with a high level of data transaction. As a matter of fact, a well-organized information system is a foundation for a proper material flow in the SC.

2.3. Buyer–Seller Relations

The buyer-seller relation is the main aspect of an SC. While traditional approaches to the buy-sell process focus on factors like the price in the buyer-seller relation, the SC draws attention to quality, R&D, cost reduction, customer satisfaction, and partnerships. In an SC, both external and internal resources are important. Consequently, the relations are not established based just on the price and cost. In the design of new products, for instance, Early Supplier Involvement and Concurrent Engineering (Dowlatshahi, 1997) are new concepts which are applied to the SC and lead it to a holistic and comprehensive approach. Some other aspects of the SC which make it different from traditional approaches are long-term contracts with suppliers and distributors, emphasizing the value adding activities, strategic alliances and information sharing.

3. Fuzzy Systems Modeling and SC Systems

Usually SC systems contain several subsystems with unlimited relations and interfaces. Each subsystem usually contains uncertainties. Petrovic *et al.* (1999, p. 444) demonstrate the uncertainties in SC systems as follows:

> "...A real SC operates in an uncertain environment. Different sources and types of uncertainty exist along the SC. They are random events, uncertainty in judgment, lack of evidence, lack of certainty of evidence that appear in customer demand, production and supply. Each facility in the SC must deal with uncertain demand imposed by succeeding facilities and uncertain delivery of the preceding facilities in the SC..."

Clearly, uncertainties of each subsystem or element make the whole system uncertain. However, the nature of interfaces in SC systems causes an SC system to operate in a completely imprecise environment. These interfaces are embedded in the material flows, information flows, and suppler-buyer relations. In the past three decades, material flows, which are related to inventory control, transportation, and the like, have been investigated by several researchers (Berry, 1972; Blackstone *et al.*, 1982; Finch and Cox, 1989; Fogarty *et al.*, 1991; Goyal and Gopalakrishnan, 1996; Hariga, 1998; Veral and Laforge, 1990). Furthermore, information flows, Management Information Systems (MISs), Decision Support Systems (DSSs), manufacturing information systems, etc. have also been other areas of interest for several researchers in the last two decades (Blanchard and Fabrycky, 1981; Jackson and Browne, 1992; Murdick *et al.*, 1990).

Thus, in addition to its integrated perspective, what makes the new SC approach deals with relationships between different elements of such a chain (Maloni and Benton, 1997). Moreover, relations between elements of the SC critically depend on human activities. This fact is one of the main reasons why emergent SC systems require fuzzy system modeling. (Sugeno and Yasukawa (1993) state "...Fuzzy algorithms are nothing but qualitative descriptions of human action in decision making..."

On the other hand, including several factors in the performance of an SCM system makes it complex. In other words, when a system uses a large amount of real data, its complexity grows exponentially. Thus, in SC system design and modeling we are to build a large-scale system with limited abilities of quantitative approaches (see Fig. 2). Türkşen (1992) states several reasons that involve the weakness of quantitative models: (i) of managers requirement of precise information; (ii) difficulties in understanding them and (iii) complexities in expressing them in the natural language of managers. The complexity of analyzing real systems increases because companies capture large amounts of data in data warehouses in this information age. Zimmermann (1996) believes that real situations cannot be described precisely and humans are not able to concurrently understand and analyze real systems. The main concept and definition of an SC system is its holistic and realistic perspective. This gives it an advantage and makes the SC different from traditional *reductionist* approaches. As a matter of fact, the SC is not just a mathematical and theoretical approach, but a real-world problem analyzer and solver. In this regard, Zimmermann states: "The usefulness of the mathematical language for modeling purposes is undisputed. However, there are limits to the usefulness and possibility of using classical mathematical language, based on the dichotomous character of set theory, to model particular systems and phenomena in the social sciences..." (Zimmermann, 1996, p. 2).

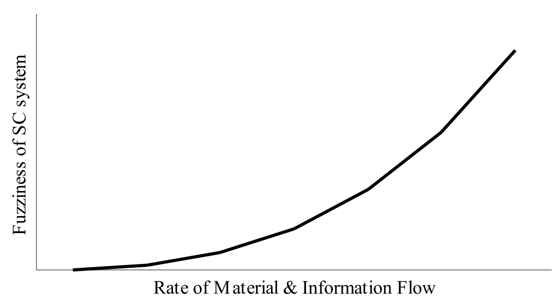

Fig. 2. Relation between the fuzziness of an SC system and material and information flows in it.

Zadeh (1973) also states: "As the complexity of a system increases, our ability to make precise and yet significant statements about its behavior diminishes until a threshold is reached beyond which precision and significance (or relevance) become almost mutually exclusive characteristics. It is in this sense that precise quantitative analyses of the behavior of humanistic systems are not likely to have much relevance to the real-world societal, political, economic, and other types of problems which involve humans either as individuals or in groups."

Summarizing, the fuzzy system approach demonstrates many advantages in real-world applications that could be expressed as follows (Türkşen and Fazel Zarandi, 1999):

(a) Fuzzy system models are conceptually easy to understand.

(b) Fuzzy system models are flexible, and with any given system, it is easy to manage it with fuzzy system models or layer more functionality on top of it without starting again from scratch.

(c) Fuzzy system models can capture most nonlinear functions of arbitrary complexity.

(d) Fuzzy system models are tolerant of imprecise data.

(e) Fuzzy system models can be built on top of the experience of experts.

(f) Fuzzy system models can be blended with conventional control techniques.

(g) Fuzzy system models are based on natural languages.

(h) Fuzzy system models provide better communication between experts and managers.

The above review shows how fuzzy concepts could help system designers to cope with the fuzzy nature of real-world situations. In a classical set, x belongs to A when $A = \{x\}$ and, consequently, it MUST NOT belong to $\sim A$ (the complementary set of A, so that $\sim A$ and A make up the universal set, i.e., $A \cap \sim A = I$ and $A \cap \sim A = \emptyset$). However, in fuzzy set theory, x belongs to a set A to some degree and ALSO x belongs to the set $\sim A$ to some degree, i.e., $A \cup \sim A \subseteq I$ and $A \cap \sim A \supseteq \emptyset$. Furthermore, as shown in Fig. 3, each number in a fuzzy set is not a crisp inflexible one, but is a member of the fuzzy set with a defined membership function (Dubois and Prade, 1980; Zadeh, 1973).

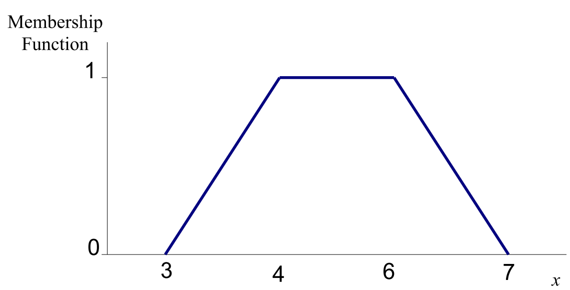

Fig. 3. A trapezoidal fuzzy number for $x : (3, 4, 6, 7)$.

Thus, fuzzy logic and approximate reasoning are powerful tools in modeling complex and imprecisely described systems such as SCs. While classically "if x is a $\Rightarrow y$ is b", fuzzy logic states such propositions as "if $\tilde{x}$ isr a $\tilde{\Rightarrow}$ $\tilde{y}$ isr b", where "isr" means "is related to" and insists on the uncertainty of model parameters (Zadeh, 1983; Zimmerman, 1996). Application of fuzzy logic in system modeling has been known to be influential. Thus, the SC as a complex system with imprecise parameters and conditions can be analyzed and modeled with the application of fuzzy set theory more appropriately.

4. Recent Trends in Fuzzy and Crisp Approaches to the SC

This section reviews the main research topics in the SC based on the main aspects of SC systems.

4.1. SC from the Material Flow Point of View

This aspect of the SC has drawn most attention of researchers in recent years. Here, some related subjects are: production planning, inventory control, scheduling problems, transportation, facility layout and location, quality management, cost accounting, and so on. For more information, see the works by Bhatnagar *et al.* (1993), Shapiro *et al.* (1993), Slats *et al.* (1995), Banerjee (1986), Bloemhof-Ruwaard *et al.* (1995), Chandra and Fisher (1994), Cohen and Lee (1988). This aspect is usually categorized as follows: (a) cost and price consideration, (b) inventory, (c) quality, and (d) other related topics in the supply chain.

4.1.1. Price Analysis through the SC

Gerchak (2000) investigates cost reduction in manufacturing processes and the supply chain by considering the uncertainties in projects. In such cases, uncertainties appear especially in time duration for each state of the project. Here, the goal is the minimization of the variability of the sum of local or partial durations, which leads to minimizing the variability of the supply chain as a whole. He and Jewkes (2000) investigate inventory costs in SCs. In this respect, they present two algorithms for computing the average total cost per product. However, these algorithms are restricted to make-to-order inventory systems. Samroengraja (1999) studies overall supply chain costs. In this approach, the use of alternated ordering policies is proposed as a strategy to cope with the order volatility. Then they examine the success of such solutions in managing orders and its empowerment in achieving a lower total cost in an SC. The results imply that reduction in the order volatility does not lead to reduction in overall SC costs. However, by applying some conditions and centralized demand information, managers and decision-makers in the SC could achieve some reductions in the total cost of an SC.

A new approach of Activity Based Costing (ABC) in cost analysis has also been widely explored in recent years. Caudle (1999) investigates the status of eleven organizations which apply ABC techniques in their logistic operations. This study tries to clarify capabilities and deficiencies of ABC in the SC. The final result of this case study indicates that "Despite the fact that most firms reported that their ABC systems were providing improved information for decision making and were worth the investment, firms were divided on whether the ABC data had resulted in improvements to their competitive positions in their respective markets." Wah (1999) presents another case study for several companies. In this study, the performance of companies through managing their SC costs is investigated, and the outcomes, which resulted from a benchmarking, are analyzed. Such results could be used as a reference for related companies.

Graman (1999) presents a different view on supply chain costs. He develops a decision cost model for determining the appropriate postponement as a supply chain strategy. This model is constructed on the content in which the packaging postponement is presented as a strategy for the SC.

The assessment of demand behavior in the SC is another main area which has high effects on cost reduction. Meixell (1999) studies some policies which provide an opportunity for reducing operating costs by developing two modeling frameworks. The first one describes the production-based decision process that drives the translation of demand and, accordingly, the SC operations. The other one examines demand behavior in technology-driven markets, where the volatile market demand exists without an integrated order processing and planning system. As a result, the demand characteristics of the larger set of scenarios can be captured using only a small fraction of the actual demand scenarios.

4.1.2. Inventory Control and Management Through the SC

Real-world production planning, inventory control and scheduling are usually imprecise. However, managers are to interact in an intelligent way with this environment. Thus they have to reach out for a new kind of reasoning based on imprecise knowledge. The major characteristics of the imprecise knowledge are as follows (Türkşen and Fazel Zarandi, 1999):

- it contains uncertainties,
- it includes errors,
- it is almost always incomplete.

Moreover, what makes this subject meaningful in SC systems is the need for an integrated approach to the flow of materials and storage of inventories. Here, integration is achieved when the inventory is viewed with other elements of the SC.

Pryor (1999) develops models in capturing inventory and transportation simultaneously. The models propose to minimize the total inventory and transportation costs. Lui (1999) investigates inventories from another viewpoint. He tries to control the inventory cost and to consider end-customer requirements. In this case, a network of inventory queues is developed, where any single queue is defined as a “queuing model that incorporates an inventory replenishment policy for the output store.” For evaluating the system performance, he decomposes the network into multiple single-stage inventory queues, and then analyzes each stage.

Petrovic *et al.* (1999) examine uncertainties in SCs by focusing on “decentralized control of each inventory” and “partial coordination in the inventories control.” They simulate and analyze some approaches to promote the SC performance in uncertainty conditions. In their former research Petrovic *et al.* (1998) tried to identify the stock level and order quantities for inventories in an SC, with the consideration of two sources of uncertainty in the SC system: “customer demand” and “external supply of raw material.” Türkşen and Fazel Zarandi (1999) describe the main challenge in fuzzy production planning and scheduling as finding a suitable realization of operations with the intersection of fuzzy constraints for the satisfaction (with a degree) of the overall requirements. In mathematical foundations of the fuzzy theory, there exists enough flexibility subject to certain axioms. In fuzzy systems, it is not difficult to merge hard and soft constraints. Moreover, the main source of difficulties in the construction of a reasonable production planning and scheduling model stems from the conflicting nature of criteria, goals and constraints. In classical scheduling methods, to reduce the problem complexity researchers often consider only a small subset of the goals, or only one criterion. However, in real applications it is reasonable to find viable compromises between conflicting objectives and goals, by determining a degree of satisfaction among the degrees of importance associated with goals, objectives and constraints. The fuzzy approach provides tools to satisfy goals, objectives, and constraints to certain degrees and to take into account the relative importance in a format easily understood by human experts. This gradual satisfaction can help schedulers to find approximately good solutions and to simplify the complexity of the production planning and scheduling problems (Türkşen and Fazel Zarandi, 1999).

Delivery uncertainties in a just-in-time environment were also surveyed by Hill and Vollmann (1986). Although uncertainties are independent of the production system, the manner in which production systems are coping with uncertainties is very important. Attempts to reduce inventory, reaching to zero defects, decreasing set up times, and the like (which are the JIT goals) in an uncertain environment are challenging issues.

The significance of agility throughout an SC system is highlighted by Christopher (2000). If agility is accepted as a key factor for a quick response organization (QRO), and if an SC system is viewed as one organization, then each subsystem of the SC should be agile in meeting client needs. While clients for SCs are end users, for each subsystem, it could be its upstream entity. Christopher examines the role of decoupling points in improving the inventory control that directly leads to agility. Mullins (1999) presents a survey on the role of storage and warehouses in supply chain management by gathering the ideas of experts and people who are engaged in existing problems in this field. Sees (1999) examines the relationship of hospital ownership and recognizes the best inventory management practices to hospital pharmacy efficiency. A questionnaire was used to gather data from hospital pharmacies belonging to multi-hospital systems. The data indicate that the ownership typology is significantly related to the measure of efficiency, with investor-owned institutions being the most efficient and government hospital pharmacies the least efficient. The data also indicate a significant relationship betwen forecasting techniques and inefficiency for investor-owned pharmacies based on the specific techniques utilized. Stapleton (1999) studies SCs in the service sector. He investigates the SC from the distribution channels standpoint. In this regard, an estimated logistics sales model is developed using the data collected from industry executives in the summer and fall of 1998. Irrespectively, the staff training is found to be a significant determinant in sales force integration. For more information about inventory management through the SC, see the works of Lee and Billington (1992), Martin *et al.* (1993), and Baganha and Cohen (1998).

4.1.3. Quality Considerations in SC Systems

Although the quality concept and its focus on product quality and the Quality Management System (QMS) are not new topics, their inclusion in the SC and its subsystems is rather new. Elinger (2000) presents potentials of supply chain management in improving the quality of the customer service. This paper investigates the role of cross-functional collaboration. Kanji and Wong (1999) present a survey on TQMs and its effect on inadequacies in current SCM models. Their SCM-TQM mix-model was tested on 139 companies in Hong Kong, and leads to the results which show the fitness of the model for SC activities. Stuart and Mueller (1994) present a case study which is focused on the Total Quality Management (TQM) and its correlation with supplier-buyer partnerships. In this case, the development of quality concepts and a system through suppliers' organizations by the construction of an alliance relationship was introduced as a TQM extension.

Marquedant (1995) demonstrates QS 9000 (a developed version of ISO 9000 customized for automotive industries) as a QMS through an SC. He studies the requirements of QS 9000 and explains their role on auto-part and service supplier performance.

Recently, QS 9000 has been considered as a global synchronizer of quality concepts through SCs in industry. Carbone (1996) indicates the use of universal quality standards as a key factor in improving the quality through an SC. Although his comment was stated for car industry, it could be generalized to all industries. He also explains some tools and procedures which are applied by Chrysler to improve the quality of suppliers. The supplier involvement from the early stages of design and the application of a computerized on-line system for the communication of quality data to suppliers in real time are some of the tools and policies implemented by Chrysler. The application of quality tools such as statistical process control (SPC) and quality function deployment (QFD) was emphasized by Original Equipment Manufacturers (OEMs) to diffuse them throughout their suppliers. Ansari and Modarress (1994) suggest a directive approach for supplier involvement in the process of the product development through the QFD method. They use personal interviews and written correspondence with corporate managers of quality in a series of companies that implement the SC. Newman (1988) also presents an analytical survey on the QFD mechanism and its usage by suppliers.

Summarizing, the development of quality concepts and their applications from the product quality through process and system qualities leads managers to expand the scope of quality into their SC. Meanwhile, regarding the qualitative character and nature of these aspects of SCs, the use of linguistic variables could be very natural. Thus, there is a potential for the application of fuzzy set theory in this area.

4.1.4. Other Related Subjects in the SC Material Flow

In addition to the main areas mentioned above, which are essential in material flow studies in the SC, there are some other interesting key fields for researchers of SCs. Lambert and Cooper (2000) focus on the logistics and critical success factors (CSFs) of the SC. They develop a conceptual framework for improving the SC management efficiency. Johnson (1999) concentrates on the distribution chain in the front end of the SC. He tries to show contents in which distributors could promote the SC performance and lead it to meet customer needs.

Another main issue in the SC is the flexibility in today's competitive markets. If a production enterprise seeks to be flexible, all its subsystems should be coordinated and flexible. Koste (1999) reviews some scales of flexibility such as handling, labor, machines, material, mix, modification, and new products. He investigates general measurement scales for flexibility. Different elements of flexibility are shown in terms of their inter-relations as well as their affect on other organizational functions.

If an SC is viewed in a total perspective, then reverse logistics could be seen as a complementary part of the material flow cycle. Electronics industry is one of the main areas facing critical troubles in recycling issues. Veerakamolmal (1999) studies scraped products after they have been used for reusable electronic components. This research argues that manufacturers have begun to realize that they must turn their attention to the development of new methodologies for reverse logistics. This interest is born not only out of environmental factors, but also for economic reasons.

Application of the SC in service and industrial sectors is also found in the works of Benson (1999), and Dzilna (1999), who discuss the magazine and journal publication industry's use of supply chain management to the manufacturing processes to allow them and their vendors to find efficiencies and cost savings.

The SCM could be considered an extension of factory scheduling (Sun, 1999). In fact, the main goal of scheduling is to synchronize the material flow between different units of an SC system. Attaining an optimal schedule of production in different industries is very hard because of conflicts between different goals. Examples of such conflicting goals are: optimization of the production rate, production quality, intra-order production, consistency, etc. Within the last thirty years or so, it has been found that the fuzzy set theory incorporated with fuzzy cluster analysis is a suitable tool to analyze and diagnoze these sorts of complicated problems (Türkşen and Fazel Zarandi, 1999). Sun (1999) also develops a Distribution Constraint Satisfaction Problem (CSP) formulation in the modeling of the SC as a total system using the fuzzy technology.

4.2. Information Flow: Status of Applications and Studies in the SC

Recently, the presence and various applications of Information Technology (IT) have improved commerce and other industrial activities. The SC, as an integrated enterprise in a large scale, has been incorporated into IT. Researchers in industries and universities are very interested in this aspect of the SC. A large amount of works published in recent years as well as software packages designed and distributed on the market show the current sympathy for IT and its applications in the SC.

Wilson (2000) investigates the application of Electronic Commerce (EC) in a high technology company. He describes potentials in tying together hubs in different industries. Stedman (2000) focuses on Internet-based application hosting services by J.D. Edwards & Co. for its enterprise resource planning (ERP) and SC management software. Bangsberg (1999) also unveils the electronic commerce services of Federal Express Corp. in Asia. He investigates the importance of combining e-commerce with the SCM. The boosted information flow between FDX Corp. and SAP AG is studied and reported by Atkinson (1999b). She displays the escalation of the IT applications. Building blocks of such a system require transmission protocols and so on, and this was investigated in her work.

In a more conceptual way, Lancioni (2000) emphasizes the Internet's role in determining the success of SCs. He investigates the adoption of companies' strategies to IT for improving their efficiency and effectiveness. He also demonstrates the SC as a multi-dimensional discipline in business management. Lancioni and Smith (2000) analyze the role of the IT in supply chain management. Increasing the use of the World Wide Web among business enterprises as well as IT, effects on the cost reduction and quality improvement are being focused on in their work. In such a viewpoint, the effective information flow in a modernized manner and using the state-of-the-art technology (IT) is a competitive weapon for a world-class company.

Gilbert (1999) demonstrates vendors' attempts in the SC to improve web procurement software. Parkes (1999) discusses in a similar way several SC management resources in the Internet. Ayers (1999) analyzes the IT-SC inter-relationship from a total perspective. He illustrates the evolution of SCM and its supportive systems through becoming dependent on inter-enterprise information. However, the SC is viewed from an IT standpoint as a Web-based system. Such a system generally involves large-scale coordination of applications, information flows, and data interchange. Thus, Chi (1999) simulates the fulfilment of a large-scale web application design with a web SC system. Irrespectively, he proposed two methodologies: the so-called Integrated Web-Enabled Application Prototype (IWEAP) and Executable Literature Document Prototype (ELDP). The IWEAP tries to integrate heterogeneous applications, manage information and interchange data by using approaches to correlate specific problem domains. On the other hand, the ELD addresses issues included in "combining human literature documents" and "systems automation" to create knowledge bases to support the decision-making process. Mallya (1999) focuses on the EDI (Electronic Data Interchange) application in the SC, too. He demonstrates the production-planning operation in the SC and explains that manufacturing lots and their scheduling depend on demands, which are "the planned dispatches to various locations in different periods from the production facility." He argues that "in an EDI environment, one can take advantage of these inter-relationships by integrating the vehicle routing, inventory management and production planning decisions for all commodities at all locations, in order to minimize the total logistic cost." In this study, mixed integer programming and Lagrangian relaxation were used. Mallya (1999) also develops the Demand Driven Production and Distribution (DDPD) operation concept which is defined for a multi-commodity production strategy. Rassameethes (1999) investigates the role of EDI in automotive SCs. His survey presents the analysis results of 180 cases related to EDI, 97 questionnaire surveys to first-tier supplies in the United States, and three in-depth case studies regarding future directions of EDI in the automotive industry. It also examines the reasons for suppliers not using EDI. The results of the research are as follows: "(a) The size of a firm does not affect the degree of EDI integration, (b) Firms with high corporate performance have a high level of EDI integration, (c) firms with high corporate performance have a high level of information sharing with suppliers, and (d) US automakers are directing first-tier suppliers to use EDI, yet first-tier suppliers have not been able to enforce its use by their suppliers."

Bartholomew (2000) developed Advanced Planning and Scheduling (APS) software for the SC in production planning. Olson (1999) demonstrates a new world competition between the SC to the SC rather than organization to organization. In this respect, he investigates successes and failures of IT tools, like EDI, in SCs. There are two main reasons that restrict good design and operation of EDI systems: the "cost prohibitive nature of EDI systems", and the "unsuccess and negligence of companies in modifying their processes." Brunelli (2000) presents a long-term horizon of IT applications and demonstrates the state of the e-commerce technology. He predicts an epidemic situation for business to business IT technology in an SC. He also claims that while currently most e-commerce systems concentrate on the automating purchase and supply of low-value products, the systems would move into areas such as "direct production goods" and "collaborative design." Fitzgerald (2000) also surveys top purchasing professionals in large companies. He assesses that most major buying organizations are in the early stages of implementing their e-procurement strategies. Porter (2000) presents a model showing that the collision of e-procurement with strategic supply management might change business relationships in the coming decade.

The use of IT in the SC is viewed in another way by Atkinson (1999a). She surveys shipping companies and third-party logistics providers to the Internet. Experiences of some oriental companies helps the author in her analysis. She describes advantages and risks in the use of the Internet by such companies. Prater (1999) discusses the role of the information flow and IT in the SC. He studies three particular aspects of global operations including the modeling of firm operational structures as they grow, the requirements of an agile international SC, and effects of logistics outsourcing on firms. He develops a model with four key variables which test a firm's SC dynamics: "Information Technology Capability", "Global SC Structure", "Global Operating Strategy", and "Global Experience."

4.3. Buyer-Seller Relations

Recently, many researchers have investigated buyer-seller relations in the SC. They state that this aspect of the SC is a new development. It is because of this fact that the material and information flows have been traditionally considered for years, while various relations in the modern production and business environment have been changing. The consideration of uncertainties in such relations, even if we assume them to be crisp, makes this aspect of the SC different from the conventional view of production systems. Strategic sourcing, supplier partnership, risk analysis in such partnering, and the use of the new generation of operation research models, the so-called soft OR in SC relations, are the main topics in this field.

Monczka *et al.* (1998) investigate success factors in strategic supplier alliances. Their article mainly focuses on buying a company and views such alliances from a buyer's point of view. In a similar way, Stuart (1993) surveys influencing factors in supplier partnerships, as well as potential and strategic benefits of such a policy.

Ohmae (1989) defined a global logic of strategic partnerships and alliances. The main contents of such alliances are the "world competition", a "need to market expansion and finding or developing new markets" and some other related topics in the business planning process. Dwyer and Schurr (1987) also surveyed developments in buyer-seller relationships. Purchasing partnerships are reviewed in the content of managerial guidelines by Ellram (1991a; 1991b), and characteristics of partnering are also surveyed by Ellram and Hendrick (1995). Graham *et al.* (1994) studied the long-term strategic impact of partnerships on purchasing. The quality improvement, supplier participation in the product development, information sharing, etc. are some of the main advantages in such partnerships. Heide and John (1990) pursued alliances in industrial purchasing. These alliances that are in a wider scope than partnerships lead supply chains to unification and coordinated operation.

Research on SC partnerships and evolution of buyer-supplier relationships are also presented by Landeros and Monczka (1989), Matthyssens and Van den Bulte (1994), MacBeth and Ferguson (1994), Landeros *et al.* (1995), and Leavy (1994).

Brown (1999) describes some critical points between manufacturers and their suppliers. He argues that "in order to ensure the future availability of capacity at a subcontractor, manufacturers must often enter into inflexible arrangement that require firm's reservations months or years in advance." Such an arrangement should provide a higher capacity availability with lower financial liability. He also explains some supplier-oriented co-operations. This arrangement tries to construct a relationship which saves both supplier and buyer benefits. Such a relation leads to a long-term collaboration called Win-Win, in which all parties are satisfied. The other is the collaborative partnership between two manufacturers that use the

Table 1. Categorized aspects of the SC.

Supplier-Buyer Relations	Information Flow	Material Flow			
		Inventory Control	Cost Analysis	Quality Consideration	Other Related Areas
Monczka *et al.*, 1998	Wilson, 2000	Pryor, 1999	Gerchak, 2000*	Newman, 1988	Sun, 1999
Stuart, 1993	Stedman, 2000	Lui, 1999	He and Jewkes, 2000	Marquedant, 1995	Koste, 1999
Ohmae, 1989	Bangsberg, 1999	Petrovic *et al.*, 1999*	Samroengraja, 1999	Carbone, 1996	Johnson, 1999
Dwyer and Schurr, 1987	Atkinson, 1999b	Petrovic *et al.*, 1998*	Caudle, 1999	Ansari and Modarress, 1994	Lambert and Cooper, 2000
Ellram, 1991a 1991b	Lancioni, 2000	Hill and Vollmann, 1986*	Wah, 1999	Stuart and Mueller, 1994	
Ellram and Hendrick, 1995	Lancioni and Smith, 2000	Christopher, 2000	Graman, 1999	Kanji and Wong, 1999	
Graham *et al.*, 1994	Gilbert, 1999	Mullins, 1999	Meixell, 1999	Elinger, 2000	
Heide and John, 1990	Parkes, 1999	Martin *et al.*, 1993			
Landeros and Monczka, 1989	Ayers, 1999	Lee and Billington, 1992			
Matthyssens and Van den Bulte, 1994	Chi, 1999	Baganha and Cohen, 1998			
MacBeth and Ferguson, 1994	Mallya, 1999				
Landeros *et al.*, 1995	Bartholomew, 2000				
Leavy, 1994	Prater, 1999				
Brown, 1999	Atkinson, 1999a				
Chakravarty and Martin, 1988	Porter, 2000				
Greenemeier, 1999	Fitzgerald, 2000				
Jones, 1999	Brunelli, 2000				
Dyer, 1996	Olson, 1999				

same subcontractor. In this case, each manufacturer independently reserves the capacity with the subcontractor and agrees to sell the excess capacity to some other manufacturer in the arrangement. Chakravarty and Martin (1988) also develop a model for the optimization of buyer-seller discount pricing.

In a case study, Greenemeier (1999) focuses on the alliance formed by KMPG LLP and FDX Corp. to provide professional and integrated services for companies to optimize supply chain management. He also studies FDX applications that KMPG plans to resell, benefits of the alliance to FDX, etc. The alliance between KMPG and FDX was also studied by Jones (1999). The other noteworthy case study was presented by Dyer (1996). He critically surveyed the Chrysler supply chain and its attempt at establishing an American and European Keiretsu.

Table 1 presents a categorized perspective of a wide range of studies on the SC. Works which focus on uncertainties and fuzzy characteristics of the SC are marked with a star.

5. Conclusion

In this survey, we discussed the main aspects of the SC. Research, scientific papers and projects in this area were classified based on their main characteristics: material flow, information flow and buyer-supplier relationships.

Moreover, we categorized crisp and fuzzy SCs. It is shown that classical SC systems cannot come up with the imprecision and uncertainty born out of human components in these systems. Fuzzy set theory, by assigning membership functions to the inputs and outputs of SC system models, has a great potential to resolve main aspects of real-world SC systems which are generally in conflict with each other.

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