Title: Revisiting supply chain dynamics: Potentials, Challenges and Future developments
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Abstract

In this paper, we review the recent trends of supply chain management and analyze how diverse modeling techniques such as agent technology, petri nets, fuzzy logic and data mining can be applied to support dynamic supply chain configuration. The literature is examined from two perspectives. First, the existing information systems that support supply chain dynamics at operational and strategic levels are discussed. Second, a synchronized supply chain strategy, with its inherent focus on web-enabled collaboration among supply chain partners is also elaborated. Also, the issues relating to integration of core processes across organizational boundaries through improved communication, partnerships, alliances and cooperation in vague and uncertain conditions is addressed. This study reviews a select set of recent and classic literature in supply chain management and in doing so provides some clear guidelines for the conduct of future research.

Keywords: Supply chain dynamics, multi-agent systems, petri nets, fuzzy logic, agent negotiation

1. Introduction

The focus of supply chain management has shifted from production efficiency to customer-driven and partnership synchronization approaches. To implement this strategic shift requires high-level collaboration between supply chain partners. A supply chain is a dynamic process and involves the constant flow of information, materials, and funds across multiple functional areas both within and between chain members (Jain *et al.* (2004, 2005, and 2006a)). Member enterprises in the chain need to cooperate with their business partners in order to meet customers' needs and to maximize their profit. Managing multiparty collaboration in a supply chain, however, is a very difficult task because there are so many parties involved in the supply chain operation, each with its own resources and objectives. There is no single authority over all the chain members. Cooperation is through negotiation rather than central management and control. The interdependence of multistage processes also requires real-time cooperation in operation and decision-making across different tasks, functional areas, and organizational boundaries in order to deal with problems and uncertainties. The strategic shift of focus for mass customization, quick response, and high quality service cannot be achieved without more sophisticated cooperation and dynamic formation of supply chains.

Although information plays a major role in effective functioning of supply chain networks, there is paucity of studies that deal specifically with the dynamics of supply chains. This problem is relatively new as faster communications over the internet or by some other means and the willingness to employ it for effective management of supply chains did not exist a few decades ago. Thus, the issue of dynamic configuration of supply chains needs serious research attention (Jain *et al.* 2006b). Due to highly complex nature of large supply chains, designing, analyzing and re-engineering of supply chain processes using formal and quantitative approaches are very difficult. Modeling and analysis of such a complex system is crucial for performance evaluation and for comparing competing supply chains. Several leading researchers, such as (Vander Aalst (1998), Lin and Shaw (1998) etc), have developed some frameworks and models to design and analyze the supply chain processes. These existing models are either oversimplified or just qualitatively described (some of them are based on simulation study (Petrovic (2001)), and are difficult to be applied for evaluating real supply chains with quantitative analysis and decisions. Since today's manufacturing enterprises are more strongly coupled in terms of material, information and service flows, there exists a strong urge for process oriented approach to address the issues of integrated modeling and analysis. All previous studies neglected significant impacts of such integration issues because of dramatic increase in modeling complexity required. Therefore, models from past studies are confined in their capability and applicability to analyze real supply chain process. An integrated formal and quantitative model, addressing the above mentioned issues that allow supply chain managers to quickly evaluate various design and operation alternatives with satisfactory accuracy, becomes imperative (Jain *et al.* 2006a). The objective of this paper is to identify the potentials and challenges for modeling dynamics in the management of supply chain. The rest of the paper is organized as follows: In section 2, we discuss the information systems for supply chain management. Section 3 discusses the issues related to synchronization of supply chain. Section 4 highlights the future developments in modeling supply chain dynamics. Finally, the concluding observations are given in the last section.

2. Information Systems for Supply chain management

In the past, mainframe-based legacy systems were used to support transactional processes within a department such as order entry, inventory control, and accounting. These transaction processing systems were isolated and implemented using incompatible hardware and software. There was lack of integration across functional areas even within a single company. There are different information systems to support SCM from early less-sophisticated legacy systems to more advanced SCM systems (see Table 1 for summary). With advanced information and communication technology, it is possible that real-time information will flow between all participating members of the supply chain such that national boundaries become virtually non-existent. The integration of isolated supply chain functions into a global system and the coordination of multiple functions across the system is the need.

Different decision support tools exist for local decision making, for example, planning and scheduling systems, inventory management systems, market trading optimizations systems etc. A mere electronic integration of these tools would not solve the problem and there is a need for unified approach for modeling and analysis of supply chain, which explicitly captures the interactions among enterprises and within departments of an enterprise. Such an approach would enable integrated supply chain decision making. Supply chain management by its very nature has all the above domain characteristics. A supply chain consists of suppliers, factories, warehouses, distribution centers and retailers, working together to convert raw materials to products and delivered to the customers. Parties involved in the supply chain have their own resources, capabilities, tasks, and objectives. They cooperate with each other autonomously to serve common goals but also have their own interests. A supply chain is dynamic and involves the constant flows of information, materials, and funds across multiple functional areas both within and between chain members. There are already a variety of information systems and networks working within and between chain members to facilitate the flows of materials, information and funds. However, there is lack of coordination and integration between these systems. Agent technology therefore is very suitable to support collaboration in supply chain management. A multi-agent system (MAS) consists of a group of agents that can take specific roles within an organizational structure. Different types of agents may represent different objects, with different authority and capability, and perform different functions or tasks. Therefore, MAS based approaches for supply chain modeling are proposed by various researchers (Swaminathan *et al.* (1998), Julka *et al.* (2002). Agent technology is the preferable technology for enabling a flexible and dynamic coordination of spatially distributed entities in supply chains. This technology changes the metaphor for human-computer interaction from direct manipulation by the user to indirect management of background agent processes because intelligent agents can autonomously perform a lot of coordination and everyday tasks on behalf of their users. Jennings *et al.* (1998) provides an overview of research and developments in the field of autonomous agents and multi-agents systems.

Supply-chain problems may also be due to natural disasters, labor disputes, supplier bankruptcy, acts of war and terrorism, and other causes. They can seriously disrupt or delay material, information and cash flows, any of which can damage sales, increase costs — or both. Broadly categorized, potential supply chain risks include delays, disruptions, forecast inaccuracies, systems breakdowns, intellectual property breaches, procurement failures, inventory problems and capacity issues. Sodhi (2005) discusses managing demand risk in tactical supply chain planning for a global consumer electronics company. Gan *et al.* (2005) addressed the issue of coordination in supply chains involving risk-averse agents. A supply chain could consist of anywhere from two over several stages (example manufacturers, suppliers, assembly, retailers) and every of these stages could possible involve several entities, holding jurisdiction over their respective area of accountability, geographically dispersed in time and space. Hence, it has become extremely essential for channel masters to incorporate risk management tools in the management of their supply chains. There is still a long way to go to implement a truly intelligent agent application. Nwana and Ndumu (1999) outline several issues, including the information discovery problem, the communication and ontology problem, the legacy software integration problem, and the reasoning and coordination problem. These issues also need to be solved before any meaningful application of agent technology in supply chain management. The limitations of agents are given in Figure 1.

2.1 The rationale of using petri nets for supply chain networks

Supply chain networks are discrete event dynamical systems (DEDS) in which the evolution of the system depends on the complicated interaction of the timings of several discrete events such as the components arrival at the suppliers, the departure of the truck from the supplier, the beginning of an assembly at the manufacturer, the arrival of the finished goods at the customer, payment approval by the seller etc. The system's state changes only at discrete events in time. In workflow systems, there are no stocks, transport is timeless, and all tasks are executed for a single case. This indicates that in many situations (but not always) the typical physical constraints do not apply. Nevertheless, deadlocks, dangling tasks, etc. are still possible. Therefore, verification and validation analysis is needed. Moreover, the execution of tasks (activities) takes time and resources are limited. Therefore, performance analysis is also useful. This calls for the use of a grounded theory research approach. Petri nets (PN's) are frequently used for modeling both information systems and business processes. PN's are particularly well suited for modeling and analyzing large and complex systems like SCN's for several reasons: they have an intuitive graphical representation; they are executable; hierarchical models can be constructed; it is possible to model the time used by diverse activities in a system; and mature and well-tested tools exist for creating, simulating, and analyzing PN Models. Analytical models, such as Markovian models, can provide exact results regarding the performance of a system. The results are exact, in that they are not estimates of the performance of the system. Still, the results provided by analytical models may or may not be accurate, depending on the assumptions of the model. In many cases it is difficult to accurately model industrial-sized systems with analytical models.

PN's are a graphical and mathematical modeling tool to describe and study information processing systems. PN with a powerful modeling and analysis ability are capable of providing a basis for variant purposes, such as knowledge representation and reasoning mechanism (Scarpelli *et al.* 1996), knowledge acquisition and knowledge verification (Wu and Lee 1997). In order to provide a vehicle for dynamic modeling and analysis of supply chain operations in vague and uncertain environments, (Jain *et al.* 2005) proposed a fuzzy enhanced high level petri net model. For a decade, researchers have enhanced the conventional PN's to involve imprecise or uncertain information. An important role has been played by PN's in the modeling field. The advantages of Petri nets have been identified and comparisons have been made with other models by several researchers (Zhou and Jeng (1998), Jeng *et al.* (1998)) etc. Decades of innovative research have enhanced its capability to handle intricacies of modeling system. Various extensions of PN's include Stochastic nets (Jain *et al.* 2003), colored stochastic PN's (Jeng *et al.* 2000) and colored timed object oriented PN's (Wang *et al.* 2000). The advantages of Petri nets have been identified and comparisons have been made with other models by several researchers (Wang *et al.* 2004; Lin *et al.* 2005) etc.

3. Developing synchronized relationships between supply chain partners

Supply Chain Synchronization is fast becoming the most important way to develop higher levels of supply chain competitive advantage. The key to genuine business growth is to emphasize the creation of an effective supply chain with trading partners, while at the same time maintaining a focus on the consumer. Today, instead of simply focusing on reducing cost and improving operational efficiency, more efforts are put on customer satisfaction and the enhancement of relationships between supply chain partners. The supply chain as a concept and as a reality is moving far beyond the confines of an individual organization. It has become a dynamic process that involves the simultaneous acquisition and continuous reevaluation of partners, technologies, and organizational structures. The overall objective of synchronized supply chain initiatives is to make it more profitable for all the parties involved. Supply chain partners need to evaluate their relative strengths and capabilities openly and critically. An implicit requirement is to "open the books" of a firm to managers outside the corporate boundaries so that cross-company and cross-functional teams can analyze cost structures and performance metrics. The following issues are dealt in this paper:

3.1 Supplier Selection

With the increase in use of quality management and JIT concepts by a wide range of firms, the supplier selection decision has become even more critical (Muralidharan *et al.* 2002). As customer's demands are always uncertain, manufacturers tend to manage their suppliers in different ways leading to a supplier-supplier development, supplier evaluation, supplier selection, supplier association, supplier coordination etc (Chan (2003), Deng and Elmaghraby (2005)). In recent years, several proposals for supplier-related problems have been reported in the literatures, as given in Table (2).

<<Include Table 2 about here>>

Chan (2003) proposed a model named Interactive Selection Model (ISM) with AHP to handle the supplier selection process (SSP) systematically and quantitatively. However, the calculation of preference among criteria is mainly based on some quantitative business data and the subjective judgment from senior level (Ghodsypour and O'Brien 1998, Verman and Pullman 1998), Field experts (Cheng and Li (2001), Humphreys *et al.* (2001) and project team (Ragatz *et al.* 1997). Because of imprecise nature of linguistic attributes, the decision of those decision makers may be subject to ambiguity. When supplier ranking is carried out by pair-wise comparison based method such as AHP and Conjoint Analysis, the results are prone to judgmental error. Moreover, use of AHP is clearly not straightforward for most users and it makes the process quite cumbersome. Also, heavily based on the principle that experience, knowledge and judgment of decision makers are atleast as valuable as the data they use, but human judgment is always subjective and has bias towards their own intuitive thought processes. Table 3 provides a comparison of various supplier evaluation methods.

<<Include Table 3 about here>>

Nowadays, from manufacturer's point of vision, customers turn out to be increasingly influential in terms of purchasing and bargaining power. In this association, manufacturers have to co-operate or interact with suppliers to maximize the productivity at the smallest cost while satisfying customer requirements. Further, the participation of a large number of narrowly interrelated assessment regarding negotiations, financing, distribution, procurement and product quality assurance at the source implies the significance and long lasting impact of suppliers selection on sourcing. Companies in order to accomplish the goals of low cost, consistent towering quality, flexibility and quick response have increasingly considered superior supplier selection approaches. These approaches require collaboration in sharing costs, benefits, expertise, and in attempting to understand one another's strength and weaknesses, which in turn leads to single sourcing and long-term partnerships (Bhutta and Huq 2002).

Dzever (2001) recognized numerous factors, which impact supplier selection decisions of organizational buyers. These factors include:

- The composition and functional specialization of the members of the decision-making units.
- The responsibility of intermediaries in the decision process
- Patterns of buyer-seller interaction and relationships
- The impact of environmental factors such as:
    - Market configuration
    - Technology
    - Economic and cultural effects on these decisions

In addition, three dimensions of buyer behavior identified also influence purchase decisions:

- Commercial,
- Technical, and,
- Social

It is thus by having a truthful understanding of these factors that one can fully appreciate the assessment process of organizational buyers in a wider perception. Supplier selection process is an inherently multi objective problem, because usually many tangible and intangible factors (price, quality, delivery performance, service etc) needs to be considered and evaluated in selecting suppliers and monitoring their performance (Talluri and Sarkis 2002). The source selection decision is highly complex because

- When choosing between the available suppliers, such a design involves more than one selection criteria.
- Criteria incorporated in the supplier selection process may frequently contradict each other (lowest price against poor quality).
- Also, the internal policy constraints and externally imposed system constraints placed on the buying process.

After scanning plethora of literatures, it seems that multiple dimensions and criteria must be used in the evaluation of supplier performance during supplier selection.
These mentioned criteria's structure a backbone of a generic supplier selection mechanism as shown in Table 4.
<<Include Table 4 about here>>

3.2 Buyer Supplier relationships

To sustain successfully in today's market place, companies need to effectively manage several key areas: the efficiency of supply chain management, management of materials, information and financial flow within the supplier/manufacturer/customer network (Ellaram and Zsidisin 2002). One of the most prevalent issues, among several which followed the introduction of E-Commerce systems, is the ability to establish a dynamic and flexible structures for buyer-supplier relationships which deterministically drive both parties toward strategic partnerships and coordination. Before moving to a marketplace, most buyers and suppliers will have existing relationships that must be reflected in the marketplace. Suppliers can configure the system to reflect pre-negotiated discounts for certain buyers, which will automatically be applied when those buyers access the market place. This many-to-many marketplace combines the advantages of both sell-side and buy-side models, but since it is hosted, avoids setup and maintenance costs for the participants. Significantly, this can allow access to smaller organizations that would not otherwise have had the resources for B2B trade online. Both buyers and suppliers gain the advantage of a much broader trading community. Both sides can also enjoy the benefits of a streamlines trading process (Mahadevan, 2002). ***From the point of view of electronic commerce, it is essential to recognize some of the elements of buyer-seller relationships that particularly seem to affect the development of electronic systems. Interdependency between companies, their bargaining power and product at hand are these kinds of important elements relevant.***

3.2.1 The analysis of relationship and relationship drivers

The growth of relationship orientation of marketing in post-industrial era is the rebirth of direct marketing between producers and consumers. Several environmental and organizational development factors are responsible for direct relationships between producers and consumers. At least five macro-environmental forces can be identified:

- Rapid technological advancements, especially in information technology;
- Adoption of total quality programs by companies;
- Growth of the service economy;
- Organizational development processes leading to empowerment of individuals and teams; and
- Increase in competitive intensity leading to concern for customer retention.

These forces are reducing the reliance of producers, as well as consumers, on middlemen for affecting the consummation and facilitation processes. According to (Tang *et al.*, (2001)), the other part's dominance will affect the buyer-seller interaction, for example, so that companies with significant bargaining power will attempt to hinder the weaker part's effort to develop new products or search for new business partners. Several industrial buyers and sellers began to develop longer-term contracts for supplies and service, creating on-going interactive relationships between themselves. Some of them engaged in long-term partnerships and formed alliances with other companies. An increasingly complex world has forced businesses to develop new ways of interacting with their customers or suppliers. Three interconnected forces are pushing firms to rethink the basic buying process.

- First, the need to maintain core capabilities while still building product becomes more difficult as the complexity within products increases, the push for lower and lower costs.
- Second, the drive for lower and lower costs is pushing firms to new relationship models and
- Third, rapidly changing technology challenges firms to focus on what core capabilities they will keep in house and what capabilities they will acquire through partnerships or relationships.

The day-to-day interaction between the individuals makes it easier to see opportunities for improving the overall system. They share the common goal of improving the total system not just their piece of it. Both the integrative and facilitative relationships emerge from the traditional transaction relationships as buying firms who seek partner relationships usually start by extending the relationship with the best of their current transaction partners. ***Both the buyer and seller extend the relationship to a new level of interdependence and cooperation in achieving mutual goals. It is important to understand what happens to the marketing and sales function as these relationships evolve in deeper relationships.***

4. Future Developments

The area of MAS is not well represented in the literature yet and an accepted theoretical framework for research and analysis has not emerged. Most research on agent systems for supply chain management is still in the early stage of theoretical framework or demonstrative prototyping. There is a long way to go. While we still have many theoretical problems to discuss, real word applications, even simple ones, will be very valuable to provide more in depth insight. The primary objective of the work is to propose a generic modeling and analysis approach that integrates functions, capture all process-related information including activities, resources and organizational units as well as their interdependencies to support complex dynamics and distributed supply chain processes.

The concept of e-negotiation support has fascinated considerable research attention and resulted in a number of applications. Recently, features of multiattribute theory, game theory, group decision making are utilized by negotiation support models as an underlying concepts to help decision makers in resolving the conflicts, which can lead to some exposure to risk or achieving agreement in a timely manner as to avoid any serious consequences. E-negotiation support systems can support collaboration between decision makers, geographically dispersed in space and time in a supply chain networks. To support e-negotiation, MAS has been extensively used, as it permits use of autonomous agents to act on behalf of human decision makers, who are dispersed geographically, to structure a community (called MAS or agency), which:

- Forbid them to communicate with each other to complete a task
- Grasp some information pertaining to the open and dynamic environment and
- Employ certain actions to effect the open and dynamic environment

Despite the availability of decision support tools to help the decision makers produce reliable policies; there is still a high degree of uncertainty in the process because of the amount and quality of subjective judgment exercised by decision maker in selecting and interpreting the most relevant information. Not only the automatic recognition of a potential conflict between decision makers originating within each jurisdiction in a dynamic SCN's but also the ability to make proposed changes and to share such changes between the decision makers is the need. The literatures lack a system that support electronic mediation or e-negotiation to capture decisions in a timely manner to alert supply chain decision makers of potential danger, perform minimal changes to effect decisions at boundary.

Although many research papers have been published and many promises have been made, we do not have a framework to understand what is the right role that the agent technology could play in supply chain management and what are the major problems and issues we have to solve for the success of applying agent technology in the real world of supply chain. Also, the literatures lack models with a strong mathematical foundation and an intuitive graphical representation for online monitoring and control system for implementing deadlock avoidance in dynamic supply chain networks. Also, there is scarcity of models which compare the expressive power of existing systems, prove properties, formalize new concepts, and analyze different interactions in supply chain dynamics. The literatures lack frameworks and algorithms to aid the decision makers by enhancing the flexibility in making decisions for evaluating suppliers with both tangibles and intangibles attributes. The literatures lack essential elements to recognize some of the elements of buyer-seller relationships that particularly seem to affect the development of electronic systems. With reference to the reported research, which involves distributed modeling of a supply chain, a higher-level coordination mechanism is not specified (Chan and Chan, 2004; Chan *et al.* 2004).

The flowchart of the select issue for supply chain dynamics is shown in Figure 2.

5. Concluding remark

In this paper, we review the recent trends of supply chain management and analyze how diverse modeling techniques such as agent technology, petri nets, fuzzy logic and data mining can be applied to support dynamic supply chain configuration. The literature is examined from two perspectives. First, the existing information systems that support supply chain dynamics at operational and strategic levels are discussed. Second, a synchronized supply chain strategy, with its inherent focus on web-enabled collaboration among supply chain partners is also elaborated. Also, the issues relating to integration of core processes across organizational boundaries through improved communication, partnerships, alliances and cooperation in vague and uncertain conditions is addressed.

Variables in a supply chain include customer demands, processing yields, raw material and finished goods delivery times, product failure and return rates, and storage capacities. Each of these can cause ripples in our supply chain and thus needs to be monitored and checked to understand the interdependencies in the supply chain. The need is to develop viable modeling methodologies and analyzing algorithms for dynamic supply chain networks so that the logic properties of supply chain process models can be analyzed and verified.

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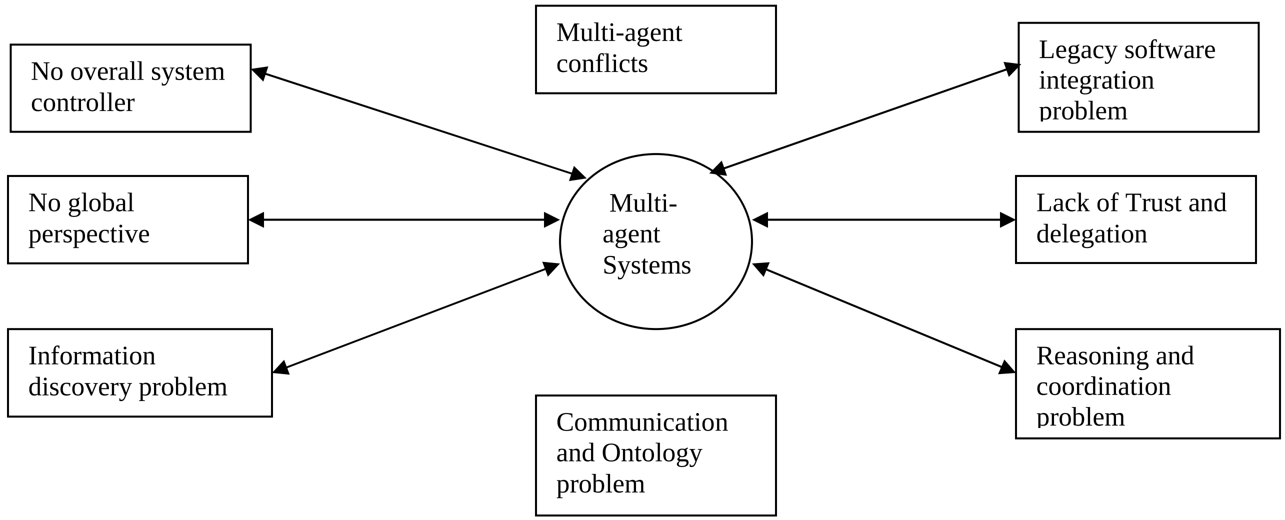

Figure 1: Limitations of Multi-agent systems

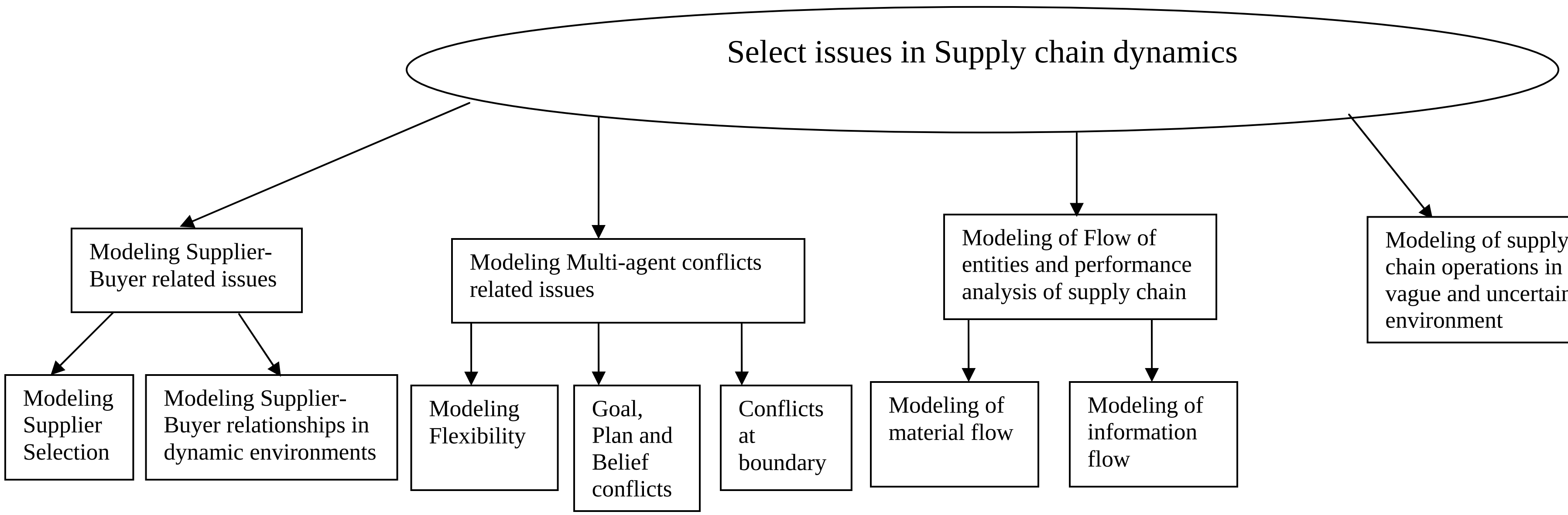

Figure 2: Select issues in supply chain dynamics

Table 1: Summary of Information Systems for SCM

Systems	**Objectives and functions**	**Limitations**
Electronic Data Interchange (EDI)	Electronic data interchange between trading partners	Only exchange transaction data with pre-arranged partners
Enterprise Resource Planning (ERP)	Integrate functional areas within enterprise at the operational level	Intra-enterprise focus, weak analytical capabilities
Supply Chain Management (SCM) systems	Analytical tools for advanced planning and strategic decisions in SCM	Lack of integration with ERP system
Business-to-Business (B2B) and Business-to-Consumer (B2C) electronic commerce	Electronic marketplace that enables business transaction with customers and suppliers through Internet	Lack of intelligent support for business collaboration through Internet
Multi-Agent System	Support and automate collaboration in SCM	• Lack of coordination mechanisms • No overall system controller • No global perspective • Trust and delegation • Information and discovery problem • Communication and ontology problem
Proposed multiagent models • Negotiation to Coordinate mechanism (N2C) (Jain *et al.* 2006b) • e-Negotiation based framework • Petri net based Multiagent framework	• A higher-level coordination mechanism with respect to distributed modeling of supply chains is provided in N2C. • It provides a system that support electronic mediation or e-negotiation to capture decisions in a timely manner so as to avoid any critical damage. It enhances automated collaboration among supply chain decision makers to diminish inconsistencies in both the development and outcome of boundary conflict resolution. • The proposed model ensures a high degree of flexibility; it avoids deadlocks and increases the parties willingness to a compromise. Through the verification analysis, some anomalies such as deadlock and congestion can be avoided in modeling supply chain dynamics.	• Only in the research stage
Petri net	Petri nets with a powerful modeling and analysis ability are capable of providing a basis for variant purposes, such as knowledge representation, reasoning mechanism, knowledge acquisition and knowledge verification	Parallel computing: the mathematical analysis of Petri nets frequently requires the solution of extremely large systems of equations The major limitation is the precise level of expressiveness of the nets

		that can be studied, and the forms of analysis the tool will permit.
Proposed Petri net models • High Intelligent Time (HIT) petri net (Jain *et al.* 2006) • Fuzzy Enhanced High Level (FEHLPN) petri net (Jain *et al* 2005)	• HIT petri net is capable of capturing supply chain dynamics, concurrency and parallelism of processes as well as asynchronous operations • The proposed FEHLPN combines a strong mathematical foundation, which effortlessly models essential aspects of rule-based systems, such as conservation of facts, refraction, and closed-world assumption. It is also able to include mechanisms for dealing with uncertainty or imprecision within the representation tool, thus permitting a better and more realistic modeling of the supply chain processes. • The integration of Petri nets with probabilistics reasoning to reap the benefits of both formalisms in detecting the conflicts. PPN is used to model a multi-agent system and detecting goal, plan and belief conflicts concurrently and dynamically.	• Only in the research stage

Table 2: Literature for supplier related problems

Methodology	Authors
Discrete Choice Analysis (DCA)	Verman and Pullman (1998)
Evolutionary fuzzy based approach	Jain *et al.* (2004)
Criteria Selection	Ghodsypour and O'Brien (1998), Humphreys *et al.* (2001), Muralidharan *et al.* (2002)
Case Studies	Barbarosoglu and Tazgac (1997), Krause and Ellram (1997)
Analytical Hierarchy Process (AHP)	Ghodsypour and O'Brien (1998), Chan (2003)
Dimensional analysis (DA)	Humphreys *et al.* (2001)
Cost Based Method	Youssef *et al.* (1996)
Data Envelopment Analysis (DEA)	Liu *et al.* (2000)
Criteria Relation	Mandal and Deshmukh (1994)
PROMETHEE method	Babic and Plazibat (1998)
Linear Programming (LP)	Ghodsypour and O'Brien (1998)
Tournaments	Deng and Elmaghraby (2005)

Table 3: Advantages and Limitations of various supplier evaluation methods

Method	Advantages	Limitations
Categorical	• Can include both qualitative and quantitative criteria • Easy implementation • Lowest implementation cost • Requires minimum data	• Equal weight to all criteria • Subjective
Weighted point plan	• Simple to understand • Easy implementation	• Subjectivity of the decision maker in the identification of weights • Assumption of ordinal scale as cardinal scale • All factors need to be expressed in standardized or normalized units
Mathematical programming	• Can guarantee optimum solution • Objective evaluation	• Difficult to include multiple decision makers • Requires arbitrary aspirations levels • Objective function coefficients should be determined prior to making the model • In LP/MIP. Many objectives are regarded as constraints, since their formulations allow only one objective function
Cost approach	• Cost control oriented • Bias can be eliminated • Allows to quantify internal production problems caused by supplier • Objective evaluation	• Requires lot of data • Complex approach requiring a comprehensive cost accounting system to generate the precise cost data needed • High implementation cost • Can deal with only relatively small number of criteria • May not be useful in comparing supplier performance because of the difficulties inherent in translating all aspects of supplier performance into precise cost figures • Difficult to include multiple decision makers
Vendor profiles analysis	• Incorporates uncertainty in the assessment procedure	• It may not be able to structure complex problems • Giving weights to various criteria is subjective • The interpretation of the resulting distribution of scores happens by judging modus, variance, and overlap
Statistical	• Uncertainty can be incorporated	• Assumption of distributions • Difficult to grasp as they involve complex computational features
Vendor performance index (VPI)	• Each criterion can be measured in its own units • Single measure of supplier performance • Can be used as an assessment	• Rating and weighting system is subjective • It is impossible to obtain a zero score on a criterion since division by zero is not defined

Table 3 (continued): Advantages and Limitations of various supplier evaluation methods

	criterion for continuous evaluation	
Standardized unitless rating (SUR) index	• Single measure of supplier performance	• Rating and weighting system is subjective • Cannot use the score for continuous assessment
Multi-criteria group decision making model	• Inclusion of multiple decision makers • Can include both qualitative and quantitative criteria • Structuring of complex problems • Can be conducted either by face to face meeting or by postal questionnaire	• Subjectivity in rating the suppliers
Analytic Hierarchy Process (AHP)	• Hierarchical representation of a system can be used to describe how changes in priority at upper levels affect the priority of criteria in lower levels. • Stable and flexible, stable in that small changes have a small effect and flexible in that additions to a well structured hierarchy do not disrupt the performance • The suppliers performance can be monitored or atleast visible to the buyer to a certain extent leading to better management of suppliers	• Use of statistical method is clearly not straightforward for most users and it makes the process quite cumbersome • Cannot effective takes into account risk and uncertainty in assessing the suppliers potential performance because it presumes that the relative importance of criteria affecting suppliers performance is known with certainty • This may be a time consuming activity as consensus may need to be reached by reviewing of the models with team members • Characteristic property of AHP is that it is fully compensatory that this might not always be realistic. In addition, the assumption of comparability is not valid due to lack of information or unwillingness to compare two alternatives with respect to some criterion i.e. it is costly to obtain necessary information
Proposed method	• Fuzzy association rules described by the natural languages are well suited for the thinking of human subjects. • It increases the flexibility for supporting users in making decisions • The goal of knowledge acquisition is achieved for users by checking fuzzy classification rules.	• The refinement the membership functions of linguistic variables by using various machine learning techniques is the scope for future work

Table 4: Supplier Selection Criteria

Criterion	Factors	Criterion	Factors
Cost	• Price • Logistics costs (Transportation, Inventory, Administration, Customs, Risk and damage, Handling and Packing) • Operating costs • After sales service costs	Relationship	• Visitation to supplier facilities • Amount of past business • Compatibility across levels and functions of buyer and supplier firms • Business references • Supplier's customer base • Financial stability • Strategic contribution • Reliability • Expectation of continuity • Dependability • Need identification ability • Cultural similarity • Negotiable ability • Trust and partnership • Ability to maintain commercial relations • Supplier availability • Industrial relations • Risks
Quality	• Quality performance (e.g. ISO 9000 accreditation • Marketability • Durability • Ergonomic qualities • Flexibility of operation • Simplicity of operation • Reliability	Organization	• Current technology (Product, Process) • Future technology (e.g., investment in R&D) • Management capability • Geographical location • Environment performance (e.g. ISO 14001 certification) • Human Resource Practices • Supplier Management • Financial Management Systems • Production facilities and capacity • Position in the industry and reputation • Performance history • Physical size/growth • Technological capabilities • Innovativeness • EDI capability
Service	• Reaction to demand • Ability to modify product • Supply variety • Technical support • After sales services (e.g. Warranties and Claims policies) • Flexibility (Payment, Freight, Price reduction, Order frequency & amount) • Delivery frequency		
Cycle Time	• Speed to market • Delivery lead time • Development Speed • On time delivery • Fill rate		