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New Approaches for Modeling and Evaluating Agility in Integrated Supply Chains

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1. Introduction

In the exisiting hotly competitive environment, companies/enterprises/organizations are interesting by the following question: How to provide the desired products and/or services to customers faster, cheaper, and better than the competitors?. Managers have come to realize that they cannot do it alone; rather, they must work on a cooperative basis with the best organizations in their supply chains in order to succeed. Moreover, the emerging global economy and the advent of IC technologies have significantly modified the business organisation of enterprises and the way of doing business. New forms of organisations such as extended enterprises, virtual enterprises, long supply chains etc. appeared and are quickly adopted by most leading enterprises. It is more and more noticed that "Competition in the future will not be between individual organizations but between competing supply chains" (Christopher, 2004). More and more business opportunities are captured by groups of enterprises in the same supply chains. The main reason for this change is the global competition that force enterprises to focus on their core competences (i.e. to be what you do the best and let others do the rest). According to the visionary report of Manufacturing Challenges 2020 conducted in USA, this trend will continue and one of the six grand challenges of this visionary report is to ability to reconfigure manufacturing enterprises rapidly in response to changing needs and opportunities.

While alliances like supply chains represent tremendous business opportunities, they also make related enterprises face greater uncertainties and risks. First supply chains are subject to market volatility and will have to be modified or dissolved once the business opportunities evolve or disappear. Changes or major perturbations at one enterprise will propagate through the supply chains to other enterprises and hence adversely influence the overall performance of the supply chains/networks. These issues are particularly important for SMEs. SMEs have to be part of some supply chains for business opportunities but they are not strong enough to face high uncertainties and risks, which are very common in today's dynamic and volatile markets. The capabilities to evaluate agility, benefits, performances, risks, etc. of supply chains are crucial for the long term efficiency and thus need serious research attentions.

Existing in both service and manufacturing activity sectors, generally speaking, a supply chain includes the transition and transportation of material from raw form through several

stages of manufacturing, assembly and distribution to a finished product delivered to the retailers and/or the end customers (Jain *et al.,* 2006). In addition to the material flows, it also includes the flows of information and finance. Each stage of material transformation or distribution may involve inputs coming from several suppliers and outputs going to several intermediate customers. Each stage will also involve information and material flows coming from immediate and distant preceding and succeeding stages.

Supply chains in general and integrated supply chains in particular are complex systems and their modeling, analysis and optimization requires carefully defined approaches /methodologies. Also, the complexities may vary greatly from industry to industry and from enterprise to enterprise. Since technological complexity has increased, supply chains have become more dynamic and complex to manage. *Consequently, it is easy to get lost in details and spend a large amount of efforts for analyzing the supply chain. On the other hand, it is also possible to execute too simplistic analysis and miss critical issues, particularly using tools that do not take into account agility, uncertainties, risks, etc.*

It is important to recognize that supply chain power has shifted from manufacturer to retailer, and finally to consumer (Blackwell & Blackwell, 2001). Most of the supply chain researchers and practitioners have agreed that there is a real need to develop integrated supply chains significantly more flexible, responsive and agile than existing traditional supply chains. It is essential that supply chains continually re-examine how they can compete and agility is one of the underlying paradigms to enable them to re-invent the content and processes of their competitive strategies. The main objectives of this chapter is to discuss *two new approaches for modeling and evaluating agility in dynamic integrated supply chains.* The rest of the chapter is organized is as follows: Section 2 deals with the complexities of integrated supply chains. Section 3 discusses the need for agile integrated supply chains. Section 4 presents the two novel approaches. Finally, section 5 concludes the chapter with some perspectives.

2. Integrated supply chains complexities

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 customer. 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. Traditional supply chain management (structural and operational strategies) are more incompetent and integration between all supply chain partners is essential for the reliability and durability of the chain. Therefore, more and more companies in different sectors like automotive, textile, grocery, petrochemical etc. are giving much more emphasizes on the integration of all their supply chain partners.

Integrated supply chains are dynamic complex processes, which involves the continuous flow of information, materials, and funds across multiple functional areas both within and between chain members. Each member of the integrated supply chain is connected to other parts of the integrated chain by the flow of materials in one direction, the flow of information and money in the other direction. Changes in any one of these integrated chain members usually creates waves of influence that propogate throughout the integrated supply chains. These waves of influence are reflected in prices (both for raw materials, labor,

parts, and finished product), flow of materials and product (within a single facility or between facilities within the supply chain), and inventories (of parts, labor capacity, and finished product). Besides its effectiveness, integrated supply chain management is a difficult process because of the stochastic and dynamic nature, multi-criterion and ever-increasing complexity of integrated supply chains. Due to highly complex nature of integrated supply chains, designing, analyzing and re-engineering of integrated supply chain processes using formal and quantitative approaches seems to be very difficult (Jain *et al.*, 2006, Ding *et al.*, 2006).

Several researchers, such as Evans *et al.*, 1995, Vander Aalst, 1998, Lin and Shaw 1998, etc. have developed some frameworks and models to design and analyze the supply chain processes. These models are either oversimplified or just qualitatively described (some of them are based on simulation study (Bhaskaran, 1998) and are difficult to apply for evaluating real supply chains with quantitative analysis and decisions. Because today's manufacturing enterprises are more strongly coupled in terms of material, information and service flows, there exists a strong urge for a process-oriented approach to address the issues of integrated modeling and analysis (Ding *et al.*, 2006, Jain *et al.* 2006, 2007a). Many of the past studies neglected significant impacts of such integration issues because of dramatic increase in modeling complexity. Therefore, models from past studies are confined in their capability and applicability to analyze real supply chain processes. An integrated formal and quantitative model, addressing the above mentioned issues that allows supply chain managers to quickly evaluate various design and operation alternatives with satisfactory accuracy, has become imperative (Jain *et al.*, 2007b).

Moreover, the need for agility for competitiveness has traditionally been associated with the integrated supply chains that provide and manufacture innovative products, such as high-technology industry products characterized by shortened life-cycles, a high degree of market volatility, uncertainty in demand, and unreliability in supply. Similarly, traditional, more slow moving industries face such challenges in terms of requirements for speed, flexibility, increased product diversity and customization. The next section discusses more in detail why the need for agile integrated supply chain?

3. Why agile integrated supply chain?

Agility – namely, the ability of a supply chain to rapidly respond to changes in market and customer demands – is regarded as the bearer of competitive advantage in today's business world (Yusuf *et al.*, 2004, Christopher & Towill, 2001, Gunasekaran, 1999). Based on a survey of past decade management literature, van Hoek (2001) identify the two most significant lessons for achieving competitive advantage in the modern business environment. The first lesson is that companies have to be aligned with suppliers, the suppliers' of the suppliers, customers and the customers' of the customers, even with the competitors, so as to streamline operations (Simchi-Levi *et al.*, 2003). As a result, individual companies no longer compete solely as autonomous entities; rather, the competition is between rival supply chains, or more like closely coordinated, cooperative business networks (Christopher, 1998, Lambert *et al.*, 1998). The second lesson is that within the supply chain, companies should work together to achieve a level of agility beyond the reach of individual companies. *All*

companies, suppliers, manufacturers, distributors, and even customers, may have to be involved in the process of achieving an agile supply chain (Christopher, 2000, Christopher and Towill, 2001).
Furthermore, "Agility" includes "Leanness" because a high stock or spare capacity method of providing flexibility to changing customer demands or adversity is not a viable financial option. *Since, agile manufacturing incorporates all the elements of lean manufacturing and thus lean and agile supply chains have commonality of characteristics except that the latter ascribes to additional principles and practices, which enhances its capability to balance both predictable and unpredictable changes in market demands* (Yusuf *et al.,* 2004). In a changing competitive environment, there is a need to develop supply chains and facilities significantly more flexible and responsive than existing ones. It is essential that supply chains continually re-examine how they can compete and agility is one of the underlying paradigms to enable them to re-invent the content and processes of their competitive strategy. In agility, therefore, lies the capability to survive and prosper by reacting quickly and effectively to changing markets. As a result, more recently, the agile manufacturing paradigm has been highlighted as an alternative to, and possibly an improvement on, leannessAn agile supply chain is seen as a dominant competitive advantage in today's business; however, the ability to build an agile supply chain has developed more slowly than anticipated (Lin *et al.*, 2006).

Based on a survey of past decade management literature, van Hoek (2001) identify the two most significant lessons for achieving competitive advantage in the modern business environment. One lesson is that companies have to be aligned with suppliers, the suppliers' of the suppliers, customers and the customers' of the customers, even with the competitors, so as to streamline operations (Simchi-Levi *et al.,* 2003). As a result, individual companies no longer compete solely as autonomous entities; rather, the competition is between rival supply chains, or more like closely coordinated, cooperative business networks (Christopher 1998, Lambert *et al.* 1998). Another lesson is that within the supply chain, companies should work together to achieve a level of agility beyond the reach of individual companies (van Hoek, 2001). All companies, suppliers, manufacturers, distributors, and even customers, may have to be involved in the process of achieving an integrated agile supply chain (Christopher, 2000, Christopher & Towill, 2001).

The need for agility for competitiveness has traditionally been associated with the supply chains that provide and manufacture innovative products, such as high-technology industry products characterized by shortened life-cycles, a high degree of market volatility, uncertainty in demand, and unreliability in supply. Similarly, traditional, more slow moving industries face such challenges in terms of requirements for speed, flexibility, increased product diversity and customization. Consequently, the need for agility is becoming more prevalent. These demands come, typically, from further down the supply chain in the finishing sector, or from end customers (Gunasekaran & Ngai, 2004). Some traditional companies have already elements of agility because the realities of a competitive environment dictate these changes (e.g. in sectors such as automobiles, food, textiles, chemicals, precision engineering and general engineering) (Christian *et al.,* 2001). According to Christian *et al.* (2001), this is, however, usually outside any strategic vision and is approached in an ad-hoc fashion. *The lack of a systematic approach to agility does not allow companies to develop the necessary proficiency in change, a prerequisite for agility (Lin et al., 2006).*

Kidd (1994) stated that Supply Chain Management (SCM) is a fairly well defined topic, but agility is not so well defined. Agility can be something that companies achieve without realizing it, or it can relate to issues that are difficult to quantify. The nature of the competencies implied by agility is such that they would be better considered as intangibles, similar to intellectual property, company specific knowledge, skills, expertise, etc. *In summary, SCM and agility combined are significant sources of competitiveness in the business world. Thus, it is no surprise that they are favored research areas in the academic research world (Yusuf et al., 2004, Swafford et al., 2006).*

The fact that agile attributes are necessary but not sufficient conditions for agility points to a major research issue to be addressed (Yusuf and Burns, 1999). It is essential that the attributes are transformed into strategic competitive bases of speed, flexibility, proactivity, innovation, cost, quality, profitability and robustness. More importantly, these attributes are of very little significance to practitioners unless there is a way of deploying them. In addition, the changing nature of the market requirements suggests the need for a dynamic deployment tool for evaluating agility. Integrated supply chains have realized that agility is essential for their survival and competitiveness. Consequently, there is no generally accepted method by researchers and practitioners for designing, operating and evaluating agile supply chains. Moreover, *the ability to build agile supply chain has developed more slowly than anticipated, because technology for managing agile supply chain is still being developed.*

Based on a synthesis of the literature (Sharp *et al.*, 1999, Yusuf *et al.*, 1999, Jharkaria and Shankar, 2005) and interviews of several industrial partners in the EU-I*Proms project (www.Iproms.org), the following critical questions and extracted motivations form the basis of this research work:

Some critical questions

Question 1: What precisely is agility/leanness and how it can be measured?

Question 2: How to develop an integrated agile/lean supply chain?

Question 3: How will lean and agile supply chains know what they have it, as there are no simple metrics or indexes available?

Question 4: How and to what degree does the integrated lean and agile supply chain attributes affect supply chains business performance?

Question 5: How to compare agility/leanness with competitiveness?

Question 6: How can the integrated supply chains identify the principal obstacles to improvement, if a supply chain wants to improve agility and leanness?

Question 7: How to assist in achieving agility/leanness effectively?

Some extracted motivations

Motivation 1: All companies, suppliers, manufacturers, distributors, and even customers, may have to be involved in the process of achieving an agile supply chain (Christopher, 2000, Christopher & Towill, 2001).

Motivation 2: The lack of a systematic approach to agility does not allow companies to develop the necessary proficiency in change, a prerequisite for agility (Lin *et al.*, 2006).

Motivation 3: SCM and agility combined are significant sources of competitiveness in the business world. Thus, it is no surprise that they are favored research areas in the academic research world (Yusuf *et al.*, 2004, Swafford *et al.*, 2006).

Motivation 4: Most agility measurements are described subjectively by linguistic terms, which are characterized by ambiguity and multi-possibility. Thus, the scoring of the existing

techniques can always be criticized, because the scale used to score the agility capabilities has limitations (Lin *et al.,* 2006).

Motivation 5: The fact that agile attributes are necessary but not sufficient conditions for agility points to a major research issue to be addressed (Yusuf & Burns, 1999). It is essential that the attributes are transformed into strategic competitive bases of speed, flexibility, proactivity, innovation, cost, quality, profitability and robustness.

Motivation 6: There is no methodology and tools for introducing and implementing such a complex and dynamic interactive system which incorporate both quantitative and qualitative attributes as agile supply chains (Lin *et al.,* 2006).

Motivation 7: Recently, the use of intelligent agents for supply chain management has received great attention as agent technology is the preferable technology for enabling a flexible and dynamic coordination of spatially distributed entities in integrated supply chains (Swaminathan *et al.,* 1998).

Motivation 8: Fuzzy logic provides a useful tool to deal with problems in which the attributes and phenomena are imprecise and vague (Zadeh, 1965).

Motivation 9: Relational databases have been widely used in support of business operations, and there the size of database has grown rapidly, for the agility of decision making and market prediction for varying degree of importance for agility evaluation, knowledge discovery from a database is very important for sustaining essential information to a business (Berry & Linoff, 1997).

Motivation 10: Association rules are one of the ways of representing knowledge, having been applied to scrutinize market baskets to help managers and decision makers understand which item/ratings are likely to be preferred at the same time (Han *et al.,* 2000).

4. New approaches

Motivated by the above extracted motivations and to find the answers to the aforementioned questions, which are critical to the practitioners and to the theory of integrated agile supply chains design, in this section, we will discuss two novel approaches for modeling and evaluating agility in dynamic integrated supply chains (Jain *et al.,* 2008a,b).

4.1 Fuzzy intelligent based approach

In this section, we discuss a novel approach to model agility (which includes leanness) and introduce *Dynamic Agility Index* through fuzzy intelligent agents. Generally, it is difficult to emulate human decision making if the recommendations of the agents are provided as crisp, numerical values. The multiple intelligent agents used in this study communicate their recommendation as fuzzy numbers to accommodate ambiguity in the opinion and the data used for modeling agility attributes for integrated supply chains. Moreover, when agents operate based on different criteria pertaining to agility like flexibility, profitability, quality, innovativeness, pro-activity, speed of response, cost, robustness etc for integrated supply chains, the ranking and aggregation of these fuzzy opinions to arrive at a consensus is complex. The proposed fuzzy intelligent agents approach provides a unique and unprecedented attempt to determine consensus in these fuzzy opinions and effectively model dynamic agility.

As producers, wholesalers and retailers seek more effective ways of marketing their products, they increasingly examine their supply chains for ways to reduce costs. Strategic planning of performance improvement is gaining attention in all areas of manufacturing. The reason for that is that it takes into account the long-term interest of the company in determining suitable business and operational policies. The agility in supply chains is determined by certain time variables, which we refer to here as 'agility characteristics'. These characteristics evolve in time and determine the entire behavior of the supply chains, refer Figure 1. The rate of change of these characteristics is a function of the current values of all the attributes as well as some suitable 'input' variables, like the size and numbers of teams, refereed as team formation, the level of integration of the database.
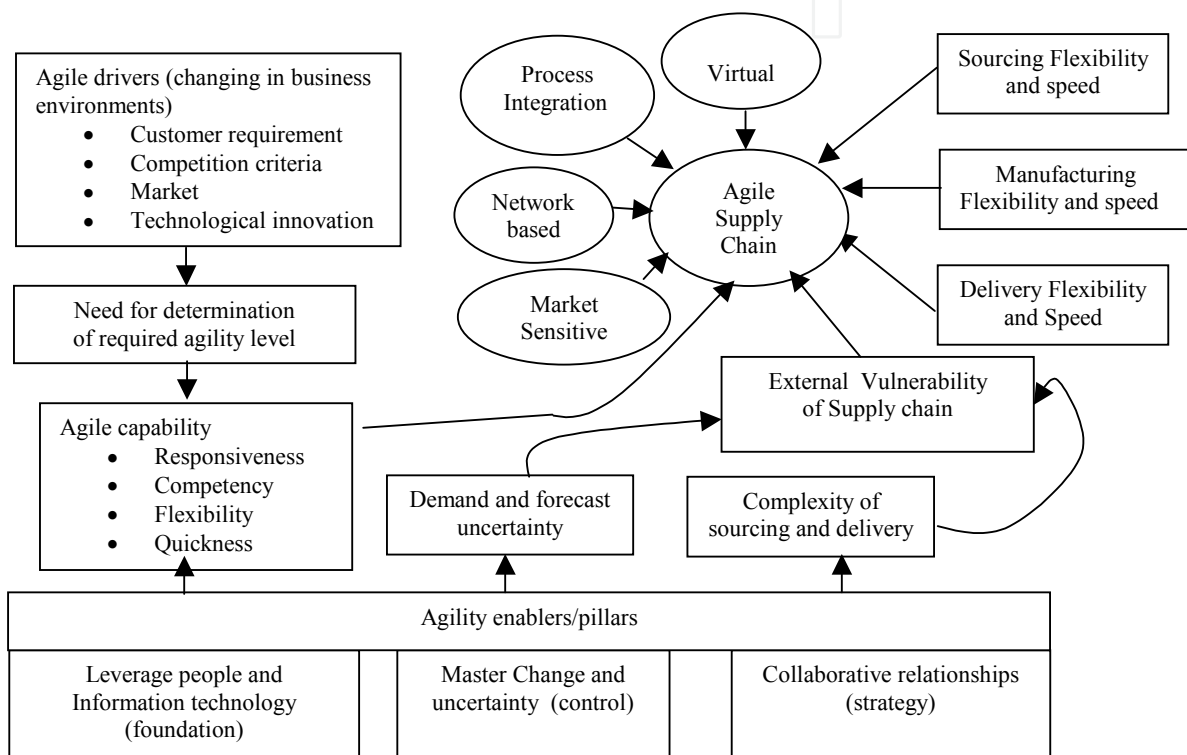

Fig. 1. The conceptual model for agile supply chains

The proposed dynamic agility index (DA$_{Li}$) of an integrated supply chain can be given a numerical value calculated as the sum of the products of suitable 'economical bases', i.e.

$$DA_{Li} = W_1 \times F_X + W_2 \times P_T + W_3 \times Q_L + W_4 \times I_V + W_5 \times P_R + W_6 \times S_R + W_7 \times C_T + W_8 \times R_B$$

Where:
- F_X is a measure of Flexibility, and W_1 is a weight assumed constant but time varying in general,
- P_T is a measure of Profitability, and W_2 is a weight assumed constant but time varying in general,
- Q_L is a measure of Quality, and W_3 is a weight assumed constant but time varying in general,
- I_V is a measure of Innovation, and W_4 is a weight assumed constant but time varying in general,

- P_R is a measure of Profitability, and W_5 is a weight assumed constant but time varying in general,
- S_R is a measure of Speed of response, and W_6 is a weight assumed constant but time varying in general,
- C_T is a measure of Cost, and W_7 is a weight assumed constant but time varying in general,
- R_B is a measure of Robustness, and W_8 is a weight assumed constant but time varying in general,

The dynamic agility index model considered in this research is shown in Figure 2.

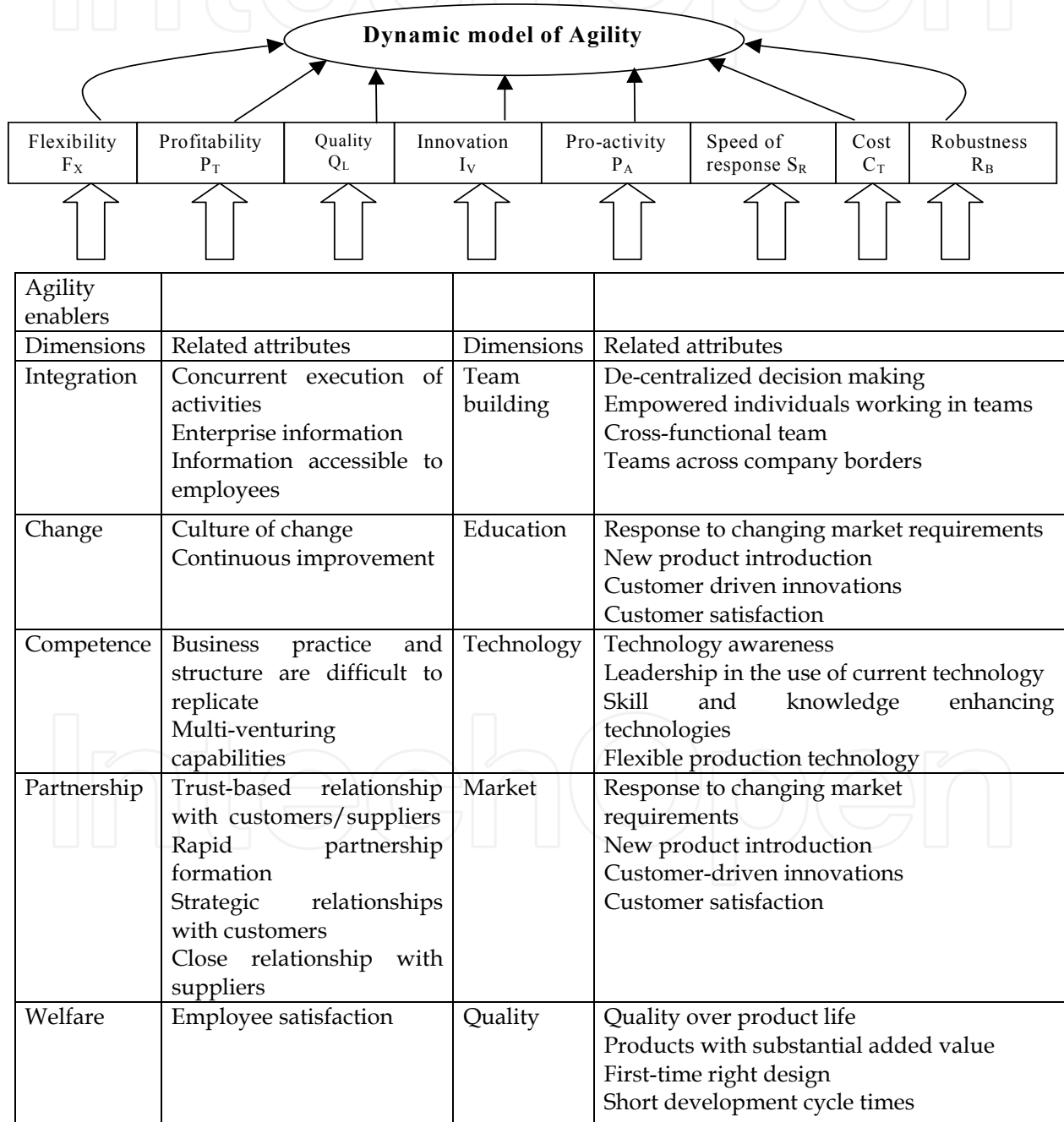| Agility enablers				
Dimensions	Related attributes	Dimensions	Related attributes
Integration	Concurrent execution of activities Enterprise information Information accessible to employees	Team building	De-centralized decision making Empowered individuals working in teams Cross-functional team Teams across company borders
Change	Culture of change Continuous improvement	Education	Response to changing market requirements New product introduction Customer driven innovations Customer satisfaction
Competence	Business practice and structure are difficult to replicate Multi-venturing capabilities	Technology	Technology awareness Leadership in the use of current technology Skill and knowledge enhancing technologies Flexible production technology
Partnership	Trust-based relationship with customers/suppliers Rapid partnership formation Strategic relationships with customers Close relationship with suppliers	Market	Response to changing market requirements New product introduction Customer-driven innovations Customer satisfaction
Welfare	Employee satisfaction	Quality	Quality over product life Products with substantial added value First-time right design Short development cycle times

Fig. 2. The proposed dynamic model for agile supply chains

The mathematical model developed is based on dynamical systems theory and recognizes that the integrated supply chains attributes have evolutionary approaches. Therefore, a new generation tools should be developed and the existing tools significantly enhanced to support decision-making processes and to deliver required solutions to extended businesses.

Now, we present the various steps of the proposed Fuzzy Intelligent agent based approach to study and model agility for integrated supply chains. More details of the proposed approach can be found in (Jain *et al.*, 2008a).

Step 1: Select criteria for evaluation. We have listed several important criteria including: Flexibility (F_X), Profitability (P_T), Quality (Q_L), Innovation (I_V), Pro-activity (P_R), Speed of response (S_R), Cost (C_T), Robustness (R_B).

"These selected eight criteria's and their possible combinations abbreviated as (C_0, C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8) are listed in Table 1. The agility of integrated supply chains can be given a numerical value calculated as the sum of the products of the aforementioned criteria and their possible combinations as given in Table 1. The eight criteria's listed above are by no means exhaustive and therefore new factors may be added depending on the product, industry and market characteristics."

Step 2: Determine the appropriate linguistic scale to assess the performance ratings and importance weights of the agility capabilities.

"Noteworthy, many popular linguistic terms and corresponding membership functions have been proposed for linguistic assessment. In addition, the linguistic variables selected to assess the importance weights of the agility capabilities are {Very High (VH), High (HG), Fairly High (FH), Medium (M), Fairly Low (FL), Low (L), Very Low (VL)}."

Step 3: Measure the importance and the performance of agility capabilities using linguistic terms.

"Once the linguistic variables for evaluating the performance ratings and the importance weights of the agility capabilities are defined, according to the supply chains policy and strategy, profile, characteristics, business changes and practices, marketing competition information, the agents can directly use the linguistic terms above to assess the rating which characterizes the degree of the performance of various agility capabilities. The results, integrated performance ratings and integrated importance weights of agility capabilities measured by linguistics variables, are shown in Table 2."

Step 4: Approximate the linguistic terms by fuzzy numbers.

"We perform trapezoidal approximations of fuzzy numbers. Tapping the properties of trapezoidal fuzzy numbers, a set of fuzzy numbers for approximating linguistic variable values was developed as shown in Table 3."

Step 5: Cumulate fuzzy opinions with fuzzy weights.

"Several aggregation techniques require that the fuzzy opinions have some intersection so that they are not entirely out of agreement. In case, the opinions do not have some agreement, the agents negotiate until they can arrive at a consensus. However, these methods will not be considered, as agents assumed in this research may intentionally have disparate recommendations due to their diverge viewpoints for supply chain management. Weighted linear interpolation is used to aggregate the opinions for every alternative, incase, there is no common interaction between agent opinions."

Combination C_0 of criteria	Combination C_1 of criteria	Combination C_2 of criteria	Combination C_3 of criteria	Combination C_4 of criteria	Combination C_5 of criteria	Combination C_6 of criteria	Combination C_7 of criteria	Combination C_8 of criteria
Flexibility (F_X)	$F_X P_T$	$P_T Q_L$	$Q_L I_V$	$I_V P_R$	$P_R S_R$	$S_R C_T$	$C_T R_B$	$F_X P_T Q_L I_V P_R S_R C_T R_B$
Profitability (P_T)	$F_X Q_L$	$P_T I_V$	$Q_L P_R$	$I_V S_R$	$P_R C_T$	$S_R R_B$		
Quality (Q_L)	$F_X I_V$	$P_T P_R$	$Q_L S_R$	$I_V C_T$	$P_R R_B$			
Innovation (I_V)	$F_X P_R$	$P_T S_R$	$Q_L C_T$	$I_V R_B$				
Pro-activity (P_R)	$F_X S_R$	$P_T C_T$	$Q_L R_B$					
Speed & response (S_R)	$F_X C_T$	$P_T R_B$						
Cost (C_T)	$F_X R_B$							
Robustness (R_B)								

Table 1. Criteria's for modeling dynamic agility

			Criteria								Weight								Rank
C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	W_0	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	R_{0-8}
F_X	$F_X P_T$	$P_T Q_L$	$Q_L I_V$	$I_V P_R$	$P_R S_R$	$S_R C_T$	$C_T R_B$	$F_X P_T Q_L I_V P_R S_R C_T R_B$	VH	VH	VH	FH	H	VH	FH	H	VH	EP
P_T	$F_X Q_L$	$P_T I_V$	$Q_L P_R$	$I_V S_R$	$P_R C_T$	$S_R R_B$			H	H	VH	H	FH	H	VH			VG
Q_L	$F_X I_V$	$P_T P_R$	$Q_L S_R$	$I_V C_T$	$P_R R_B$				VH	VH	H	VH	VH	VH				GD
I_V	$F_X P_R$	$P_T S_R$	$Q_L C_T$	$I_V R_B$					H	FH	FH	VH	FH					FR
P_R	$F_X S_R$	$P_T C_T$	$Q_L R_B$						FH	VH	H	FH						GD
S_R	$F_X C_T$	$P_T R_B$							H	M	VH							FH
C_T	$F_X R_B$								VH	FH								VG
R_B									FH									GD

Table 2. Aggregated performance rating with aggregated important weight for selected agility criteria

			Criteria						Rank
C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	R_{0-8}
F_X	$F_X P_T$	$P_T Q_L$	$Q_L I_V$	$I_V P_R$	$P_R S_R$	$S_R C_T$	$C_T R_B$	$F_X P_T Q_L I_V P_R S_R C_T R_B$	$(7, 8, 9, 10)$
P_T	$F_X Q_L$	$P_T I_V$	$Q_L P_R$	$I_V S_R$	$P_R C_T$	$S_R R_B$			$(5, 6.04, 7, 8)$
Q_L	$F_X I_V$	$P_T P_R$	$Q_L S_R$	$I_V C_T$	$P_R R_B$				$(3.49, 4.51, 5.50, 6.52)$
I_V	$F_X P_R$	$P_T S_R$	$Q_L C_T$	$I_V R_B$					$(2.52, 3.50, 4.50, 5.56)$
P_R	$F_X S_R$	$P_T C_T$	$Q_L R_B$						$(3.50, 4.50, 5.50, 6.50)$
S_R	$F_X C_T$	$P_T R_B$							$(5, 6, 7, 8)$
C_T	$F_X R_B$								$(3.52, 4.50, 5.48, 6.25)$
R_B									$(5, 6, 7, 8)$

Table 4. Ranks of dynamic agility index for selected agility criteria

Performance rating		Importance weighting	
Linguistic variable	Fuzzy number	Linguistic variable	Fuzzy number
Worst (WT)	(0, 0.05, 0.25, 1.25)	Very Low (VL)	(0, 0.005, 0.025, 0.125)
Very Poor (VP)	(1, 2, 3, 4)	Low (LW)	(0.1, 0.2, 0.3, 0.4)
Poor (PR)	(1.5, 2.5, 3.5, 4.5)	Fairly Low (FL)	(0.15, 0.25, 0.35, 0.45)
Fair (FR)	(2.5, 3.5, 4.5, 5.5)	Medium (MD)	(0.25, 0.35, 0.45, 0.55)
Good (GD)	(3.5, 4.5, 5.5, 6.5)	Fairly High (FH)	(0.35, 0.45, 0.55, 0.65)
Very Good (VG)	(5, 6, 7, 8)	High (HG)	(0.5, 0.6, 0.7, 0.8)
Exceptional (EP)	(7, 8, 9, 10)	Very High (VH)	(0.7, 0.8, 0.9, 1.0)

Table 3. Fuzzy numbers for approximating linguistic variables for selected agility criteria

Each agent, ξ, is assigned a rating, ψ_ξ. The most crucial agent is specified a rating of 1 and the others are given ratings less than 1, in relation to their significance. To the ratings the following properties holds:

Maximum $(\psi_1, \psi_2, \psi_3 ..., \psi_\delta)$ = 1

Minimum $(\psi_1, \psi_2, \psi_3 ..., \psi_\delta)$ < 1

The degree of significance (DOS) is defined as:

$$\text{DOS} = \Pi_\xi = \frac{\psi_\xi}{\sum_{\xi=1}^{\delta} \psi_\xi} \qquad \xi = 1, 2, 3, ..., \delta \tag{1}$$

The cumulated fuzzy opinion for alternative η is formed as a Trapezoidal fuzzy number (TFN) tuple ($\lambda_1, \lambda_2, \lambda_3, \lambda_4$) using formulas:

$$\begin{cases} \lambda_1 = \sum_{\xi=1}^{\delta} \Pi_\xi \lambda_{1\xi}, \quad \lambda_2 = \sum_{\xi=1}^{\delta} \Pi_\xi \lambda_{2\xi}, \\ \lambda_3 = \sum_{\xi=1}^{\delta} \Pi_\xi \lambda_{3\xi}, \quad \lambda_4 = \sum_{\xi=1}^{\delta} \Pi_\xi \lambda_{4\xi} \end{cases} \tag{2}$$

where: δ is the number of agents with opinions on alternatives η, Π_ξ corresponds to the degree of significance of agent ξ and ($\lambda_{1\xi}, \lambda_{2\xi}, \lambda_{3\xi}, \lambda_{4\xi}$) symbolizes TFN opinion of agent ξ for alternative η. The resulting inferred aggregated opinion ($\lambda_1, \lambda_2, \lambda_3, \lambda_4$) can be represented as:

$$(RI_A)^* = \sum_{\xi=1}^{\delta} \Pi_\xi (\circ) R^* \tag{3}$$

where $R^* = (\lambda_{1\xi}, \lambda_{2\xi}, \lambda_{3\xi}, \lambda_{4\xi})$ and $(\circ)$ is the fuzzy multiplication operator.

Thus, the trapezoidal fuzzy membership function is used to determine the agility level and the required fuzzy index of the selected criteria can be calculated using equation (3).

$$R_0 = \cfrac{\begin{bmatrix} (7,8,9,10)\otimes(0.7,0.8,0.9,1.0)\oplus(7,8,9,10)\otimes(0.7,0.8,0.9,1.0) \\ \oplus(7,8,9,10)\otimes(0.7,0.8,0.9,1.0)\oplus(7,8,9,10)\otimes(0.35,0.45,0.55,0.65) \\ \oplus(7,8,9,10)\otimes(0.5,0.6,0.7,0.8)\oplus(7,8,9,10)\otimes(0.7,0.8,0.9,1.0) \\ \oplus(7,8,9,10)\otimes(0.35,0.45,0.55,0.65)\oplus(7,8,9,10)\otimes(0.5,0.6,0.7,0.8) \end{bmatrix}}{\begin{bmatrix} (0.7,0.8,0.9,1.0)\oplus(0.7,0.8,0.9,1.0)\oplus(0.7,0.8,0.9,1.0) \\ \oplus(0.35,0.45,0.55,0.65)\oplus(0.5,0.6,0.7,0.8)\oplus(0.7,0.8,0.9,1.0) \\ \oplus(0.35,0.45,0.55,0.65)\oplus(0.5,0.6,0.7,0.8) \end{bmatrix}} = (7,8,9,10)$$

Applying the same equation the other fuzzy indexes of agility criteria are obtained as listed in Table 4. Finally, applying the same equation again, we calculate the proposed Dynamic Agility level index (DA_{Li}) for modeling agility for integrated supply chains with the taken 8 criteria and their all possible combinations is evaluated as:

$$DA_{Li} = \cfrac{\begin{bmatrix} (7,8,9,10)\otimes(0.7,0.8,0.9,1.0) \\ \oplus(5,6.04,7,8)\otimes(0.5,0.6,0.7,0.8) \\ \oplus(3.49,4.51,5.5,6.52)\otimes(0.7,0.8,0.9,1.0) \\ \oplus(2.52,3.5,4.5,5.56)\otimes(0.5,0.6,0.7,0.8) \\ \oplus(3.5,4.5,5.5,6.5)\otimes(0.35,0.45,0.55,0.65) \\ \oplus(5,6,7,8)\otimes(0.5,0.6,0.7,0.8) \\ \oplus(3.52,4.5,5.48,6.25)\otimes(0.7,0.8,0.9,1.0) \\ \oplus(5,6,7,8)\otimes(0.35,0.45,0.55,0.65) \end{bmatrix}}{\begin{bmatrix} (0.7,0.8,0.9,1.0)\oplus(0.5,0.6,0.7,0.8) \\ \oplus(0.7,0.8,0.9,1.0)\oplus(0.5,0.6,0.7,0.8) \\ \oplus(0.35,0.45,0.55,0.65)\oplus(0.5,0.6,0.7,0.8) \\ \oplus(0.7,0.8,0.9,1.0)\oplus(0.35,0.45,0.55,0.65) \end{bmatrix}} = (4.544,5.486,6.352,6.982)$$

Step 6: Rank the fuzzy opinions.

"The superior alternative must be chosen, once the opinions of the agents have been aggregated to produce a consensus opinion for each alternative. The findings of Nakamura (1986) emphasize a fuzzy preference function that outline a comparison index, which compares opinions k_i and k_j that accounts for the hamming distance of every fuzzy number to the fuzzy minimum and the fuzzified best and worst states."

The FFCF is defined as:

$$\mu_p(K_i, K_j) = \begin{cases} \cfrac{1}{\varpi_\beta}\begin{bmatrix} \beta\chi(K_{i*}, K_{i*}\wedge K_{j*}) \\ +(1-\beta)\chi(K_i^*, K_i^*\wedge K_j^*) \end{bmatrix} & if\ \varpi_\beta \neq 0 \\ \\ \cfrac{1}{2} & if\ \varpi_\beta = 0 \end{cases} \tag{4}$$

where :

$$\varpi_\beta = \beta\left[\chi(K_{i*}, K_{i*}\wedge K_{j*}) + \chi(K_{j*}, K_{i*}\wedge K_{j*})\right] + (1-\beta)\left[\chi(K_i^*, K_i^*\wedge K_j^*) + \chi(K_j^*, K_i^*\wedge K_j^*)\right]$$

$$\mu_{K^*}(\phi) = \underset{\{\theta/\theta \geq \phi\}}{Sup} \mu_K(\theta) \qquad \forall \phi \in V \tag{5}$$

Further, K_* is the highest upper set of K defined by:

$$\mu_{K_*}(\phi) = \underset{\{\theta/\theta \leq \phi\}}{Sup} \mu_K(\theta) \qquad \forall \phi \in V \tag{6}$$

$K_i \wedge K_j$ is the extended minimum defined by:

$$\mu_{K_i \wedge K_j}(\sigma) = \underset{\{\theta,\phi/\theta \wedge \phi = \sigma\}}{Sup} [\mu_{K_i}(\theta) \wedge \mu_{K_j}(\phi)] \forall \sigma = V \tag{7}$$

and the Hamming distance between K_i and K_j is given by $\chi(K_i, K_j)$, which is

$$\chi(K_i, K_j) = \int_\varepsilon \left| \mu_{K_i}(\theta) - \mu_{K_j}(\theta) \right| d\theta \tag{8}$$

Theoretically, $\chi\left(K_{i*}, K_{i*} \wedge K_{j*}\right)$ and $\chi\left(K_i^*, K_i^* \wedge K_j^*\right)$ signifies the advantages of K_i over K_j with respect to the fuzzified worst states and the fuzzified best states. The fraction of the weighted combination of the advantages of K_i and K_j over the worst states and the above the best states, to the sum of such weighted combinations of K_i's and s's is represented by the fuzzy first choice function (FFCF), $\mu_p(K_i, K_j)$.

In this chapter, the fuzzy first choice function compares every fuzzy opinion to a "Standard" fuzzy number, which demonstrates the case where the opinion is "Most Likely". Hence, the difficulty with existing methods suffers when comparing fuzzy numbers with identical modes and symmetric spreads is eliminated. Also, in this chapter, the fuzzy opinions are not only judge against "Most Likely" fuzzy numbers but also are already ranked in contrast to this value, thus eliminating the procedure of determining the ranking based on pairwise comparison. The result of every fuzzy first choice calculation for every node presents its ranking. The FFCF evaluating opinion K_i and the most likely mode, M, substitutes the second fuzzy opinion with M and is defined as:

$$\mu_p(K_i, M) = \begin{cases} \dfrac{1}{\varpi_\beta} \left[\begin{array}{l} \beta\chi\left(K_{i*}, K_{i*} \wedge K_{j*}\right) \\ +(1-\beta)\chi\left(K_i^*, K_i^* \wedge M^*\right) \end{array} \right] & if \ \varpi_\beta \neq 0 \\[4ex] \dfrac{1}{2} & if \ \varpi_\beta = 0 \end{cases} \tag{9}$$

The FFCF can be simplified by showing that $\chi\left(K_i^*, K_i^* \wedge M^*\right) = 0$, when M is a TFN defined as $(\lambda_1, \lambda_2, 1, 1)$. Thus, if M is signified by $(\lambda_1, \lambda_2, 1, 1)$, the modified fuzzy first choice function used to evaluate opinion K_i with the most likely mode, M, is defined as:

$$\mu_p(K_i, M) = \begin{cases} \dfrac{1}{\varpi_\beta} \beta\chi\left(K_{i*}, K_{i*} \wedge M^*\right) & if \ \varpi_\beta \neq 0 \\[4ex] \dfrac{1}{2} & if \ \varpi_\beta = 0 \end{cases} \tag{10}$$

where $\varpi_\beta = \beta\left[\chi(K_{i^*}, K_{i^*} \wedge M^*) + \chi(M_*, K_{i^*} \wedge M^*)\right] + (1-\beta)\chi(M_*, K_{i^*} \wedge M^*)$

This fuzzy first choice function is able to distinguish between fuzzy numbers with identical modes and symmetric spreads while reducing the computational complexity.

Step 7: Match the fuzzy opinions with an appropriate agility level.

"In this case the natural language expression set selected is given as: Exceedingly Agile (EA), Very Agile (VA), Agile (AG), Fairly Agile (FA), Most Likely Agile (MLA), Slowly Agile (SA), No Agile (NA). "

The Euclidean distance ED is calculated by using the Euclidean distance formula as given in Equation (11) below:

$$ED(AG_L, F_N) = \left(\sum_{x \in P} \left(f_{AG_L}(x) - f_{F_L}(x)\right)^2\right)^{\frac{1}{2}} \tag{11}$$

Where $P = \{x_0, x_1, ..., x_m\} \subset [0, 10]$ so that $0 = x_0 < x_1 < ... < x_m = 10$.

The ED for the selected set of natural expression set is given as: ED (EA)= 1.2364, ED(VA)= 0.0424, ED(AG)= 1.0241, ED(FA)= 1.1462, ED(MLA)= 1.5321, ED(SA)= 1.6422 and ED(NA)= 1.8041.Thus, by matching a linguistic label with the minimum ED, dynamic agility can be modeled with the given criteria's. From the numerical example given in (Jain *et al.,* 2008a), it can be seen that the selected eight criteria (F_X, P_T, Q_L, I_V, P_R, S_R, C_T, R_B), the supply chain falls under the Very Agile (VA) category. Depending on the selected criteria, for any supply chains, the proposed approach will help the decision makers and analysts in quantifying agility.

Step 8: Analyze and classify the main obstacles to improvement.

"Modeling agility not only measures how agile is integrated supply chain, but also most importantly helps supply chain decision makers and practitioners to assess distinctive competencies and identify the principal obstacles for implementing appropriate improvement measures. In supply chain network, the factual environment of the problem engrosses statistics, which is repeatedly fuzzy and indefinite. This is primarily owing to its imprecise interfaces and its real-world character, where uncertainties in activities starting raw material procurement to the end consumer make the supply chain unfocused. 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."

However, it is difficult to emulate human decision making if the recommendations of the agents are provided as crisp, numerical values. Intelligent agents must express their opinions in similar terms to emulate human experts. Moreover at times, the agents make their recommendations based upon incomplete or unreliable data. A second problem arises when intelligent agents base their opinions on different viewpoints. The proposed approach provides an overall picture about the possibly agility of an integrated supply chain. Although, the dynamic agility index is conveyed in a range of values, the proposed approach ensures that the decision made in the selection using the fuzzy intelligent agents will not be biased.

4.2 Fuzzy association rules mining based approach

As a second approach, we present a Fuzzy Association Rule Mining based approach to support the decision makers by enhancing the flexibility in making decisions for evaluating

agility with both tangibles and intangibles attributes/criteria such as Flexibility, Profitability, Quality, Innovativeness, Pro-activity, Speed of response, Cost and Robustness. Also, by checking the fuzzy classification rules, the goal of knowledge acquisition can be achieved in a framework in which evaluation of agility could be established without constraints, and consequently checked and compared in several details. More details of the proposed approach can be found in (Jain *et al.,* 2008b).

Mining association rules is one of the most important research problems in data mining. Many organizations have devoted a tremendous amount of resources to the construction and maintenance of large information databases over recent decades, including the development of large scale data warehouses. Frequently the data cannot be analyzed by standard statistical methods, either because there are numerous missing records, or because the data are in the form of qualitative rather than quantitative measures.

In many cases, the information contained in these databases is undervalued and underutilized because the data cannot be easily accessed or analyzed. Some databases have grown so large that even the system administrators do not always know what information might be represented or how relevant it might be to the questions at hand. Data sets commonly contain some an uncertain, particularly incompleteness and inconsistency. One example is a distributed information environment, where data sets are generated and collected from different sources, and each source may have different constraints. This can lead to different interrelationships among the items, thus imposing vagueness on the data set. Recent years have witnessed many efforts on discovering fuzzy associations, aimed at coping with fuzziness in knowledge representation and decision support process. Therefore, the necessity of applying Fuzzy Logic in data mining is due to the following:

- One is that fuzziness is inherent in many problems of knowledge representation, and the other is that high-level managers or complex decision processes often deal with generalized concepts and linguistic expressions, which are generally fuzzy in nature.
- Moreover fuzziness may prevail in many other association cases in which impression, matching, similarity, implication, partial truth or the like is present.
- The modeling of imprecise and qualitative knowledge, as well as the transmission and handling of uncertainty at various stages are possible through the use of fuzzy sets.
- Fuzzy logic is capable of supporting to a reasonable extent, human type reasoning in natural form.

A method to find the large itemsets and also an apriori algorithm is proposed in the literature (Agarwal *et al.,* 1996). However, to find the large itemsets, these algorithms should scan the database several times. Also, while they generated a candidate itemset, the apriori-gen function must have exhausted a good deal of time to confirm, if its subsets are large or not. Further, the well known methods viz. Partial completeness (Srikant and Agarwal 1996), Optimized association rules (Fukuda *et al.,* 1996) and CLIQUE (Agarwal *et al.,* 1998), divided the qualitative attributes into many crisps partitions. There were no interactions between the partitions. However, crisp partitions may be unreasonable for some situations. For example, if we tried to partition the range (70, 80 $) of the attribute "COST" for a supplier, into two partitions, then separable point was not different between 75.01 and 74.99$. Hence, interaction of any of the neighborhood partitions can be promised. Moreover, we considered that the fuzzy association rules described by the natural language as well as suited for the thinking of human subjects and will help to increase the flexibility for users in making decisions or designing the fuzzy systems for evaluating agility. Hence, we use fuzzy partition method to find the fuzzy association rules.

Fuzzy partitioning in quantitative attributes

A quantitative attribute can be partitioned into 'L' various linguistic values (L=2, 3, 4….). For example, for the attribute 'cost' (range from 0 to 100), we describe L=2, L=3 in Figures 3 and 4 respectively.

Also, ψ_{L,ϕ_V}^{COST} can be used to represent a candidate 1-dim fuzzy framework.

Then μ_{L,ϕ_V}^{COST} can be represented as follows:

$$\mu_{L,\phi_V}^{COST}(y) = Max\left\{1 - \frac{\left|y - \xi_{\phi_V}^{L}\right|}{\lambda^L}, 0\right\}$$

Where $\xi_{\phi_V}^{L} = Min_{AD} + \dfrac{(Max_{AD} - Min_{AD})(\phi_V - 1)}{(L-1)}$ and $\lambda^L = \dfrac{(Max_{AD} - Min_{AD})}{(L-1)}$.

Min$_{AD}$ and Max$_{AD}$ are the maximum and minimum of the attribute domain.
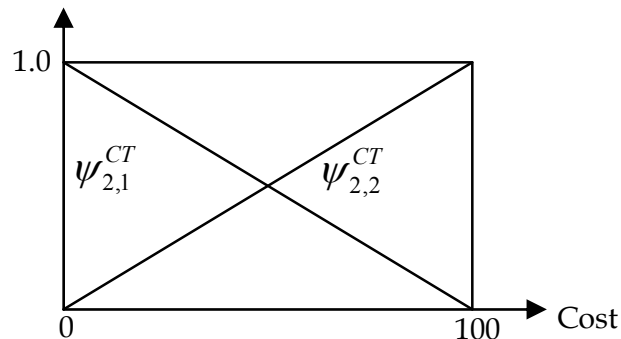
Fig. 3. L=2 for quantitative attribute cost for agility
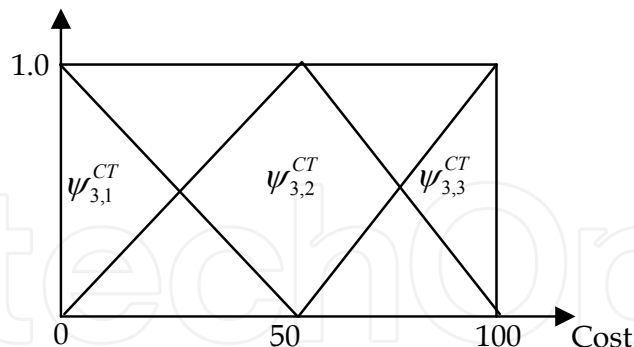
Fig. 4. L=3 for quantitative attribute cost for agility

Fuzzy partitioning in qualitative attributes

Qualitative attributes of a relational database have a finite number of possible values, with no ordering among several values. For example Flexibility (F_X), Profitability (P_T), Quality (Q_L), Innovation (I_V), Pro-activity (P_R), Speed of Response (S_R) and Robustness (R_B)). If the distinct attribute values are η' (η' is finite), then this attribute can only be partitioned by η' linguistic values. In the agility evaluation considered in this second approach, the linguistic sentences of each linguistic value defined by the attributed dependability can be stated as follows: $\psi_{2,1}^{FX} = Low$ and $\psi_{2,2}^{FX} = High$.

Each linguistic value distributed in either quantitative attribute (Cost) or qualitative attributes (Flexibility, Quality, Innovation, etc.) is considered as a potential candidate 1-dim fuzzy framework. The succeeding task is how to use these candidate 1-dim fuzzy frameworks to generate the other large fuzzy frameworks and fuzzy association rules.

Determine large fuzzy frameworks

Once all candidate 1-dim fuzzy frameworks have been generated, we need to determine how to find the other large fuzzy frameworks and fuzzy association rules. Figure 5 describes the proposed model for generating fuzzy association rules.

From figure 5, we can see that large fuzzy frameworks and fuzzy association rules are generated by stages 1 and 2 respectively. To evaluate the agility using fuzzy association rules, the algorithm is given as:

Algorithm

Given by the decision maker, the input comprises of the following specification:

1. A database containing several quantitative and qualitative attributes for evaluating agility.
2. The minimum F_ZS_P
3. The minimum F_ZC_F

The main algorithm operations comprises of 2 stages:

1. **Stage 1**: Generate large fuzzy frameworks
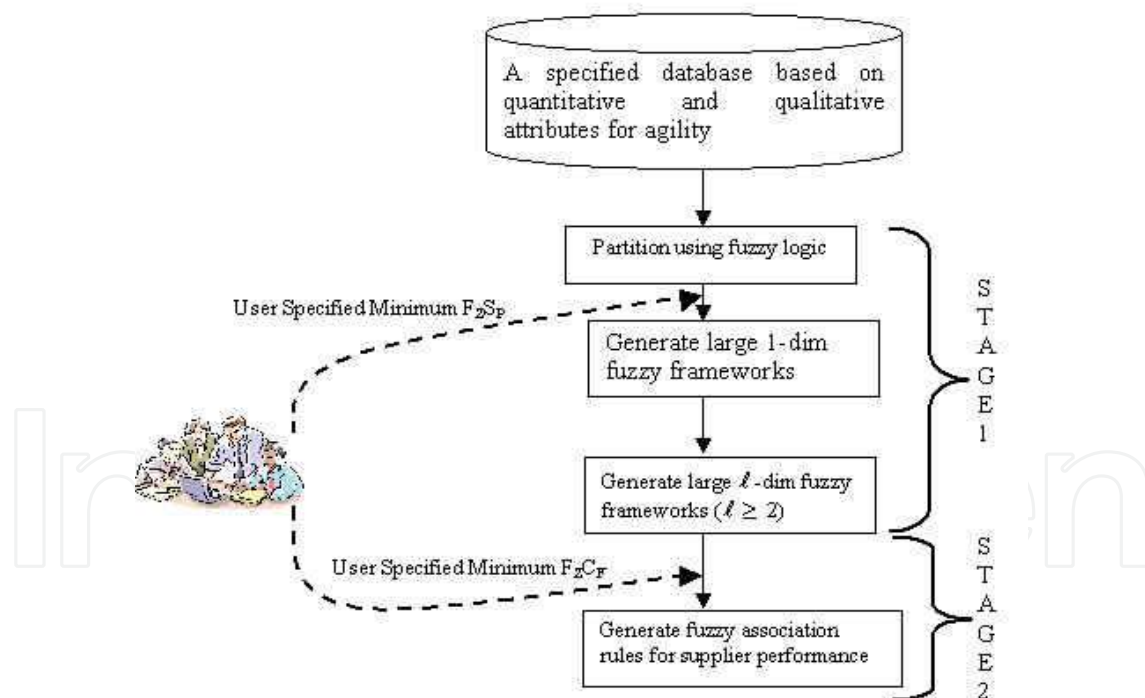2. **Stage 2**: Generate effective fuzzy association rules and evaluate the agility

Fig. 5. Two-stage model for generating fuzzy association rules

These two stages are described in detail as following:

Stage 1 (comprises of three different steps)

Begin Step 1:

        Step1.1: Generate large fuzzy frameworks

Step1.2: Perform fuzzy partition

Step1.3: Scan the database and construct the table comprising of F_ZF_T, O_PT and F_ZS_P

Step1.4: Generate large 1-dim fuzzy frameworks

Step1.5: Set $\ell = 1$ and eliminate the rows of initials (F_ZF_T, O_PT and F_ZS_P) corresponding to the candidate 1-dim fuzzy frameworks which are not large

Step 1.6: Reconstruct (F_ZF_T, O_PT and F_ZS_P)

Step 2: Generate large ℓ-dim fuzzy frameworks. Set $\ell +1$ to ℓ. If there is only one (ℓ-1)-dim fuzzy framework, then go to **Step 3** within the same stage.

For any two unpaired rows F_ZF_T O_PT F_ZS_P [Δ] and F_ZF_T O_PT F_ZS_P [σ], where ($\Delta \neq \sigma$), corresponding to large (ℓ-1)-dim fuzzy frameworks **do**

Step 2.1: **If** any two linguistic values are defined in the same linguistic variable from (F_ZF_T [Δ] OR F_ZF_T [σ]) that corresponds to a candidate ℓ-dim fuzzy framework $\prod$, **then** Discard $\prod$, and skip steps 2.2, 2.3 and 2.4. That is, $\prod$ is not valid.

Step 2.2: **If** F_ZF_T [Δ] and F_ZF_T [σ] do not share $(\ell - 2)$ linguistic terms, **then** discard $\prod$ and skip steps 2.3 and 2.4. That is, $\prod$ is invalid.

Step 2.3: **If** there exists integers $1 \leq \text{int}_1 < \text{int}_2 < ...\text{int}_\ell$ such that (F_ZF_T [Δ] OR F_ZF_T [σ]) (int₁)= (F_ZF_T [Δ] OR F_ZF_T [σ]) (int₂)=…= (F_ZF_T [Δ] OR F_ZF_T [σ]) (int ℓ -1) = (F_ZF_T [Δ] OR F_ZF_T [σ]) (intℓ)=1, **then** compute [O_PT (int₁). O_PT (int₂)… O_PT (int ℓ)] and the fuzzy support F_ZS_P of $\prod$.

Step 2.4: Add (F_ZF_T [Δ] OR F_ZF_T [σ]) to table F_ZF_T (O_PT [int₁]. O_PT [int₂]… O_PT [int ℓ] to O_PT and F_ZS_P when F_ZS_P is $\geq$ Min F_ZS_P, otherwise discard $\prod$.

Step 3: Check whether or not any large ℓ-dim fuzzy framework is generated.

If any large ℓ-dim fuzzy framework is generated,

then go to **Step 2** (of stage 1)

else go to Stage 2.

It is noted that the final F_ZF_T O_PT F_ZS_P only stores large fuzzy frameworks.

End

Stage 2 (comprises of one step)

Begin Step 1:

Step 1.1: Generate effective fuzzy association rules

Step 1.2: **For** two unpaired rows, F_ZF_T [Δ] and F_ZF_T [σ] ($\Delta < \sigma$), corresponding to a large fuzzy frameworks LAR Δ and LAR σ respectively **do**

Step 1.2.1: Produce the antecedent part of the rule. Let $\hbar$ be the number of nonzero elements in F_ZF_T [Δ] AND F_ZF_T [σ]

Step 1.2.2: **If** the number of nonzero elements in F_ZF_T [Δ] $= \hbar$, **then** LAR $\Delta \subset$ LAR σ is hold, and the antecedent part of one rule, say R, is generated as LAR σ; **otherwise** skip Steps 1.3 and 1.4

Step 1.3: Generate the consequence of the rule. Use (F_ZF_T [Δ] *XOR* F_ZF_T [σ]) to obtain the consequent part of R_L.

Step 1.4: Check or not whether rule R_L can be generated $F_ZC_P(R_L) \geq$ Min F_ZC_P, then R_L is effective.

End

The efficacy of the presented approach was demonstrated using an illustrative numerical example in (Jain *et al.,* 2008b).

5. Conclusion and perspectives

The ability to build lean and agile supply chains has not developed as rapidly as anticipated, because the development of technologies/techniques/approaches to manage such concepts of lean/agile for integrated supply chains is still under way. Also, due to ill-defined and vague indicators, which exist within leanness/agility assessment, many measures are described subjectively by linguistic terms, which are characterized by vagueness and multi-possibility, and the conventional assessment approaches cannot suitably nor effectively handle such dynamic situations.

In this chapter, firstly, we present a novel approach to model agility and introduce *Dynamic Agility Index* through fuzzy intelligent agents The proposed approach concentrates on the application of linguistic approximating, fuzzy arithmetic and agent technology is developed to address the issue of agility measuring, stressing the multi-possibility and ambiguity of agility capability measurement. Secondly, we discuss a novel approach based on *Fuzzy Association Rule Mining* incorporating fuzzy framework coupled with rules mining algorithm to support the decision makers by enhancing the flexibility in making decisions for evaluating agility with both tangibles and intangibles characteristics. Also, by checking the fuzzy classification rules, the goal of knowledge acquisition can be achieved for users.

As a scope for future work, empirical research is required to study the application of the proposed approaches and to characterize agility in integrated supply chains. Multi-functional workforce and their performance evaluation should also be studied as a scope for further research.

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Supply Chain the Way to Flat Organisation

Edited by Julio Ponce and Adem Karahoca

With the ever-increasing levels of volatility in demand and more and more turbulent market conditions, there is a growing acceptance that individual businesses can no longer compete as stand-alone entities but rather as supply chains. Supply chain management (SCM) has been both an emergent field of practice and an academic domain to help firms satisfy customer needs more responsively with improved quality, reduction cost and higher flexibility. This book discusses some of the latest development and findings addressing a number of key areas of aspect of supply chain management, including the application and development ICT and the RFID technique in SCM, SCM modeling and control, and number of emerging trends and issues.

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