

A NOVEL APPROACH TO MODEL AND EVALUATE DYNAMIC AGILITY IN SUPPLY CHAINS

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Abstract: In this paper, we propose a novel approach to model agility and introduce *Dynamic Agility Index (DA_{Li})* 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. The efficacy of the proposed approach is demonstrated with the help of an illustrative example.

1 INTRODUCTION

An 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). 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 and Ngai, 2004).

According to Kidd (1994), 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 (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 et al. 2004). 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.

There is a growing body of literature on different aspects of agility (Jain *et al.* 2008). Collectively, these contributors and many others (Kumar and Motwani, 1995), provide insights to what constitute attributes of an agile supply chain. *However, there is no methodology and tools for introducing and implementing such a complex and dynamic*

interactive system as agile supply chains (Lin et al., 2006).

Whilst the needs of integrated supply chain networks have been to a large extent identified, there is a lack of suitable and commercially available tools to satisfy these. 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. *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 two limitations:*

- Such techniques do not take into account the ambiguity and multi-possibility associated with the mapping of one's judgment to a number, and
- The subjective judgment and the selection and preference of evaluators have a significant influence on those methods.

1.1 Extracted Motivations

Based on the above discussions, we have extracted the following motivations for this study:

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 and 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 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 et al. 2004). 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).

1.2 Outlines and our Contributions

In embracing integrated agile supply chain many important questions concerning agility need to be asked (Jharkaria and Shankar 2005) such as:

- What precisely is agility and how it can be measured?
- How to develop an integrated agile supply chain?
- How will agile supply chains know what they have it, as there are no simple metrics or indexes available?
- How and to what degree does the integrated agile supply chain attributes affect supply chains business performance?
- How to compare agility with competitiveness?
- How can the integrated supply chains identify the principal obstacles to improvement, if a supply chain wants to improve agility?
- How to assist in achieving agility effectively?

Answers to such questions are critical to the practitioners and to the theory of integrated agile supply chains design. 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.

Therefore, we introduce a novel concept of *Dynamic Agility Index (DA_{L_i})* to model agility in integrated supply chains. More specifically, this paper describes an effort in developing an approach to determine a consensus without requiring that the agent opinions have any agreement for modeling agility attributes in integrated supply chains. The multiple intelligent agents used in the paper communicate their recommendation as fuzzy numbers to accommodate ambiguity in the opinion and the data used for supply chains.

2 AGILITY AND SUPPLY CHAIN

Parallel developments in the areas of agility and SCM led to the introduction of *an agile supply chain* (Christopher 2000). While agility is accepted widely as a winning strategy for growth, even a basis for

survival in certain business environments, the idea of creating agile supply chains has become a logical step for companies. Agility in a supply chain, according to Ismail and Sharifi (2005), is the ability of the supply chain as a whole and its members to rapidly align the network and its operations to dynamic and turbulent requirements of the customers. *The main focus is on running businesses in network structures with an adequate level of agility to respond to changes as well as proactively anticipate changes and seek new emerging opportunities.*

Agile supply chain concerns change, uncertainty and unpredictability within its business environment and makes appropriate responses to changes. Therefore, an agile supply chain requires various distinguishing capabilities, or “fitness”. These capabilities include four main elements:

- Responsiveness, which is the ability to identify changes and respond to them quickly, reactively or proactively, and also to recover from them;
- Competency, which is the ability to efficiently and effectively realize enterprise objectives;
- Flexibility/adaptability, which is the ability to implement different processes and apply different facilities to achieve the same goals;
- Quickness/speed, which is the ability to complete an activity as quickly as possible.

Van Hoek (2005) observes that three characteristics of supply chain operations can be earmarked as directly related to becoming agile: 1) mastering and benefiting from variance, 2) rapid responsiveness, and 3) unique or small volume responsiveness. In addition, many researchers provide conceptual overviews, different reference and mature models of agility (Christopher 2000, Yusuf *et al.* 2004, Ismail and Sharifi (2005)).

There has been quite a clear vision of the benefits of creating an agile supply chain. However, there is a shortage of studies and cases of companies actually turning the vision or ambition into reality, let alone tools that they use to do so. 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. This forms the motivation for our problem environment, which is described in the next section of the paper.

3 PROBLEM ENVIRONMENT

The agility in supply chains is determined by certain time variables, which we refer to here as ‘agility characteristics’. 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. 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:

1. F_X is a measure of Flexibility, and W_1 is a weight assumed constant but time varying in general,
2. P_T is a measure of Profitability, and W_2 is a weight assumed constant but time varying in general,
3. Q_L is a measure of Quality, and W_3 is a weight assumed constant but time varying in general,
4. I_V is a measure of Innovation, and W_4 is a weight assumed constant but time varying in general,
5. P_R is a measure of Profitability, and W_5 is a weight assumed constant but time varying in general,
6. S_R is a measure of Speed of response, and W_6 is a weight assumed constant but time varying in general,
7. C_T is a measure of Cost, and W_7 is a weight assumed constant but time varying in general,
8. R_B is a measure of Robustness, and W_8 is a weight assumed constant but time varying in general,

Let us assume that these variables form the output vector (OT) of the dynamical agility model, i.e.

$$OT = (OT1, OT2, OT3, OT4, OT5, OT6, OT7, OT8) \\ = (F_X, P_T, Q_L, I_V, P_R, S_R, C_T, R_B)$$

The mathematical model developed is based on dynamical systems theory and recognizes that the integrated supply chains attributes have evolutionary approaches.

4 THE PROPOSED APPROACH WITH AN ILLUSTRATIVE EXAMPLE

In this section, we present an illustrative example for the proposed Fuzzy Intelligent agent framework to study and model the agility for integrated supply chains. The stepwise procedure is shown as follows:

Step 1: Select criteria for evaluation. Based on the literature, we have listed several important criteria for modeling agility for evaluation of integrated supply chains. These include the following: 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).

An agile supply chain must be able to withstand the aforementioned variations and disturbances and indeed must be in a position to take advantage of these fluctuations to maximize their profits. 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. An agile supply chain means that the production process must be able to respond quickly to changes in information from the market. This requires lead time compression in terms of the flow of information and material and the ability to change at short notice, to change to a wide variety of products. In many cases, it is virtually impractical for agents to directly determine the score of a vague indicator, such as measure of quality or the speed of response or innovation. Therefore, in this research, linguistic terms are used to assess the performance rating and importance weights of the agility capabilities for integrated supply chains.

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, in case, there is no common interaction between agent opinions. 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:

$$\text{Maximum } (\psi_1, \psi_2, \psi_3, \dots, \psi_\delta) = 1$$

$$\text{Minimum } (\psi_1, \psi_2, \psi_3, \dots, \psi_\delta) < 1$$

The degree of significance (DOS) is defined as:

$$\text{DOS} = \Pi_\xi = \frac{\psi_\xi}{\sum_{\xi=1}^{\delta} \psi_\xi} \quad \xi = 1, 2, 3, \dots, \delta \quad (1)$$

The cumulated fuzzy opinion for alternative η is formed as a Trapezoidal fuzzy number (TFN) tuple $(\hat{\lambda}_1, \hat{\lambda}_2, \hat{\lambda}_3, \hat{\lambda}_4)$ using formulas:

$$\left\{ \begin{array}{l} \tilde{\lambda}_1 = \sum_{\xi=1}^{\delta} \Pi_{\xi} \lambda_{1\xi}, \tilde{\lambda}_2 = \sum_{\xi=1}^{\delta} \Pi_{\xi} \lambda_{2\xi}, \\ \tilde{\lambda}_3 = \sum_{\xi=1}^{\delta} \Pi_{\xi} \lambda_{3\xi}, \tilde{\lambda}_4 = \sum_{\xi=1}^{\delta} \Pi_{\xi} \lambda_{4\xi} \end{array} \right. \quad (2)$$

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 $(\tilde{\lambda}_1, \tilde{\lambda}_2, \tilde{\lambda}_3, \tilde{\lambda}_4)$ can be represented as:

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

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 as above equation (3).

$$R_0 = \frac{\left[\begin{array}{l} (7,8,9,10) \otimes (0.7,0.8,0.9,1.0) \oplus (7,8,9,10) \otimes (0.7,0.8,0.9,1.0) \\ \oplus (7,8,9,10) \otimes (0.7,0.8,0.9,1.0) \oplus (7,8,9,10) \otimes (0.35,0.45,0.55,0.65) \\ \oplus (7,8,9,10) \otimes (0.5,0.6,0.7,0.8) \oplus (7,8,9,10) \otimes (0.7,0.8,0.9,1.0) \\ \oplus (7,8,9,10) \otimes (0.35,0.45,0.55,0.65) \oplus (7,8,9,10) \otimes (0.5,0.6,0.7,0.8) \end{array} \right]}{\left[\begin{array}{l} (0.7,0.8,0.9,1.0) \otimes (0.7,0.8,0.9,1.0) \oplus (0.7,0.8,0.9,1.0) \\ \oplus (0.35,0.45,0.55,0.65) \oplus (0.5,0.6,0.7,0.8) \oplus (0.7,0.8,0.9,1.0) \\ \oplus (0.35,0.45,0.55,0.65) \oplus (0.5,0.6,0.7,0.8) \end{array} \right]} = (7,8,9,10)$$

Applying the same equation the other fuzzy indexes of agility criteria are obtained. 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:

$$DA_{Li} = \frac{\left[\begin{array}{l} (7,8,9,10) \otimes (0.7,0.8,0.9,1.0) \\ \oplus (5,6,04,7,8) \otimes (0.5,0.6,0.7,0.8) \\ \oplus (3.49,4.51,5.5,6.52) \otimes (0.7,0.8,0.9,1.0) \\ \oplus (2.52,3.5,4.5,5.56) \otimes (0.5,0.6,0.7,0.8) \\ \oplus (3.5,4.5,5.5,6.5) \otimes (0.35,0.45,0.55,0.65) \\ \oplus (5,6,7,8) \otimes (0.5,0.6,0.7,0.8) \\ \oplus (3.52,4.5,5.48,6.25) \otimes (0.7,0.8,0.9,1.0) \\ \oplus (5,6,7,8) \otimes (0.35,0.45,0.55,0.65) \end{array} \right]}{\left[\begin{array}{l} (0.7,0.8,0.9,1.0) \otimes (0.5,0.6,0.7,0.8) \\ \oplus (0.7,0.8,0.9,1.0) \otimes (0.5,0.6,0.7,0.8) \\ \oplus (0.35,0.45,0.55,0.65) \oplus (0.5,0.6,0.7,0.8) \\ \oplus (0.7,0.8,0.9,1.0) \otimes (0.35,0.45,0.55,0.65) \end{array} \right]} = (4.544, 5.486, 6.352, 6.982)$$

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:

$$\mu_p(K_i, K_j) = \begin{cases} \frac{1}{\sigma_\beta} \left[\beta \chi(K_{i^*}, K_{i^*} \wedge K_{j^*}) \right. \\ \left. + (1-\beta) \chi(K_i^*, K_i^* \wedge K_j^*) \right] & \text{if } \sigma_\beta \neq 0 \\ \frac{1}{2} & \text{if } \sigma_\beta = 0 \end{cases} \quad (4)$$

where :

$$\begin{aligned} \sigma_\beta &= \beta \left[\chi(K_{i^*}, K_{i^*} \wedge K_{j^*}) + \chi(K_{j^*}, K_{i^*} \wedge K_{j^*}) \right] + \\ & (1-\beta) \left[\chi(K_i^*, K_i^* \wedge K_j^*) + \chi(K_j^*, K_i^* \wedge K_j^*) \right] \\ \mu_{K^*}(\phi) &= \text{Sup}_{\{\theta|\theta \geq \phi\}} \mu_K(\theta) \quad \forall \phi \in V \end{aligned} \quad (5)$$

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

$$\mu_{K_*}(\phi) = \text{Sup}_{\{\theta|\theta \leq \phi\}} \mu_K(\theta) \quad \forall \phi \in V \quad (6)$$

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

$$\mu_{K_i \wedge K_j}(\sigma) = \text{Sup}_{\{\theta|\theta \wedge \phi = \sigma\}} [\mu_{K_i}(\theta) \wedge \mu_{K_j}(\phi)] \quad \forall \sigma \in V \quad (7)$$

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

$$\chi(K_i, K_j) = \int_{\epsilon} |\mu_{K_i}(\theta) - \mu_{K_j}(\theta)| d\theta \quad (8)$$

Theoretically, $\chi(K_{i^*}, K_{i^*} \wedge K_{j^*})$ and $\chi(K_i^*, K_i^* \wedge K_j^*)$ 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 K_j 's is represented by the fuzzy first choice function (FFCF), $\mu_p(K_i, K_j)$.

In this paper, 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 paper, 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:

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

The FFCF can be simplified by showing that $\chi(K_i^*, K_i^* \wedge M^*) = 0$, 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:

$$\mu_p(K_i, M) = \begin{cases} \frac{1}{\varpi_\beta} \beta \chi(K_{i^*}, K_{i^*} \wedge M^*) & \text{if } \varpi_\beta \neq 0 \\ \frac{1}{2} & \text{if } \varpi_\beta = 0 \end{cases} \quad (10)$$

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. Ranks for dynamic agility index for selected agility criteria are given in Table 4.

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 linguistics and the corresponding membership functions are shown in Figure 6. The Euclidean distance ED is calculated by using the Euclidean distance formula as given in Equation (11) below:

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

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

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 Figure 6, 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. 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 association, supplier coordination etc.

5 CONCLUSIONS AND PERSPECTIVES

In this paper, we propose a novel approach to model agility and introduce *Dynamic Agility Index* (DA_L) 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.

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.

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. For the numerical example considered in this study, the dynamic agility index has a fuzzy value of (4.544,5.486,6.352,6.982), which falls under Very Agile (VA) category. Thus, it gives the decision makers a high degree of flexibility in decision-making.

As a scope for future work, empirical research is required to study the application of the model developed in this paper and to characterize agility in integrated supply chains. Moreover, we are involving in European project I*Proms, with several industrial partners, we expect to apply the proposed approach to model agility in real life scenarios.

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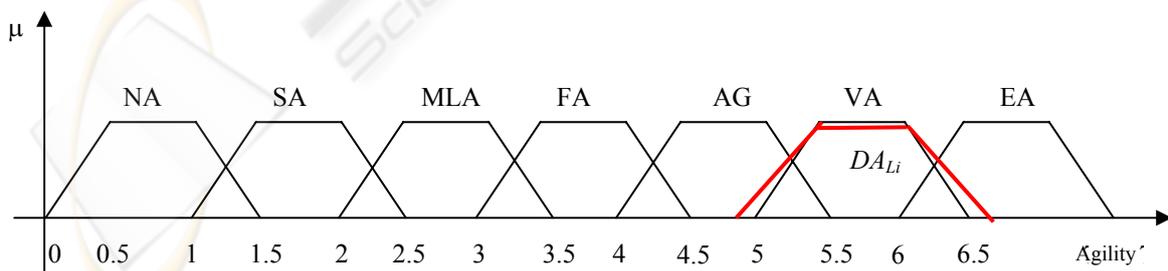


Figure 1: The proposed dynamic agility index (DA_{Li}) for the illustrative example.

Table 1: Criteria's for modeling dynamic agility.

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

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 3: Fuzzy numbers for approximating linguistic variables 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 4: Ranks for dynamic agility index 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)