Implementation of fuzzy logic to measure supply chain agility

Mehdi Karimimalayer [1,*], Nizaroyani Saibani [2]

Faculty of Engineering and Built Environment, University Kebangsaan Malaysia
[1] mehdikm@siswa.ukm.edu.my; [2] nizar@eng.ukm.my;*
** corresponding author*

ARTICLE INFO

Article history:
Received August 17, 2015
Revised October 17, 2015
Accepted November 7, 2015

Keywords:
Agility
Fuzzy Logic
Supply Chain

ABSTRACT

In our age of perennial changing environment, supply chain agility is a crucial factor having a great impact on the company's competitiveness. For transforming supply chain into an agile supply chain, first it is necessary to comprehend the meaning of agile supply chain, since agility has wide range of meaning and various dimensions which cover different aspects of an organization. Generally, however, there have been many researches on agility, proportionally; the concept of agility in supply chain has not been much surveyed. The circumstance unveils the necessity of a technique to measure the supply chain agility. The purpose of the article is to propose a technique, using fuzzy logic in which supply chain agility can be measured.

I. Introduction

Shifts in customers' demands, market's environment and technological innovations, have put the companies in an incremental competition. Such critical condition results in a review of the business priorities and strategic prospect and also a drop in reliance on the existing models. In such competitive market, developing and enhancing flexibility and responsibility is required, and regarding agility is a necessity of survival. Therefore, in order for the companies to win over the rivals in the world market, they must unite with suppliers and customers and advance their operations and activities to acquire a certain level of agility in supply chain. An agile supply chain is comprised of a group of companies that are separate from each other, while operationally are dependent on each other. These companies are related to each other by the forward flow of material and feedback flow of information. The agile supply chain insists upon the improvement in adoptability and flexibility and is able to react and respond quickly and effectively to the changes in the market. The agile supply chain is proposed as the paradigm of supply in the 21th century and is considered as the winning strategy of companies which are in pursuit of leading the market in national and international extent.

Existing approaches in supply chain agility, usually, assess the condition of internal agility features of institution using supply and demand of the network's end. These approaches attempt to physically coordinate the network with market and competition requirements, reforming the process of production in supply chain and communicational and behavioral analysis between supply chain's members. In spite of the inevitableness of agility, institutes which are active in complex environments, encounter the problem of measuring it. In such environments, usually, the supply chain is a part of institution which receives the most influence from the changes. In most instances, operational limitation of supply chain is related to its agility and it is due to this fact that supply change swiftly turns to be a restrictive factor of the whole institution. In strategic extent, supply chain agility is accounted crucial. Due to the fact agile supply chain quickly, easily and with high predictability and quality sense the changes in demand and respond to it similarly; supply chain agility determines the existence of an institution. Nevertheless, most completed researches on the topic of agile production, have disregarded the issues related to supply change management. The purpose of this paper is to provide instrument for measuring supply chain agility.

II. Literature Review

Unprecedented pressure caused by foreign products, introducing new products by rivals, drop in product's lifespan, unpredicted changes in relation to customers, improvements in production and communication technology, privatization of governmental companies, economic records and pressures forced by stockholders to return their capital, are imposed on companies. Regarding the pressure, the most important challenge which producers face, is, integrating up upper-level outsourcing performances and lower-level delivery performances [1]. One the most significant paradigmatic changes in the business management, is the shift in competition unit from institution to supply chain. Today, instead of rivalry between two trademarks, or a store with another store, suppliers of trademark of one store compete with suppliers of the trademark of another store, or in other words, one supply chain with another supply chain [2]. A formal definition is given in a few articles on supply chain agility; therefore, an agreement on main components of supply chain agility is never reached. Since there is no true understanding of supply chain components, in respect to conceptual model, diverse conceptual models for explaining the features of supply chain are employed. The conception of agility is comprised of two factors; Responding to changes (predicted or unpredicted) in a quality way and appropriate time, utilizing these changes and converting them into opportunities [3]. Hence, agility is a respond to changing and competitive environment in an institutional extent which obeys four principles: common wealth, uncertainty and change control, improving the ability of human resources and participation in competition [4] [5]. Another definition of agility is proposed as the ability of an institution in performing profitable operations in the categorized and perpetually changing market using quality production, quality operation and goods and services suitable to customers' requirements [5]. Based on [6] opinion the ability to respond quickly to the market is called agility which is defined as the key element of institutions survival [6]. Reference [7] defines supply chain agility as the ability of the supply chain in adoptability or quick responding to the changing environment of market. The considered framework by Swafford and others, process-oriented approach, in respect to organization's supply chain which is comprised of three key processes of resourcing, making and delivery / logistic [7]. Reference [8] believes that an agile supply chain should possess differentiating features; these features are shown in the fig. 1 [8]. Lin et al have proposed the following conceptual model in fig. 2 based on their review of agile supply chain literature [9]. Hence agility could be defined as "a managerial concept related to respond to the turbulent and dynamic market and customers' demands". In fact, agility is not only related to responding to the customers but also is related to utilizing the changes. It should be flexible in several fields such as product development, creating and logistic, for responding to the companies [10].

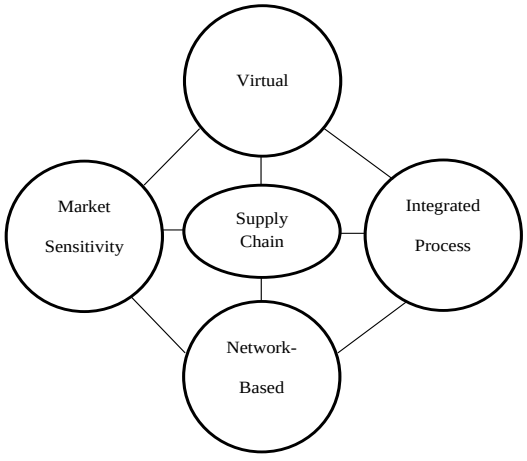

Fig. 1 Agile Supply Chain [8]

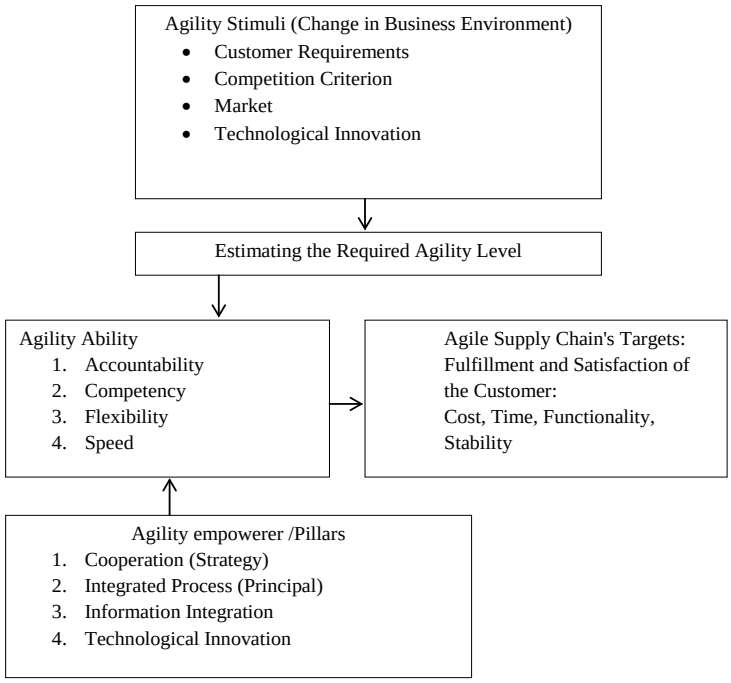

Fig. 2 Conceptual Model of Agile Supply Chain [9]

The agile supply chain includes companies that are separated from each other legally, but are dependent on each other operationally. Some of these companies are suppliers, designers, manufacturers and production centers. These companies attach to each other by the forward flow of materials and feedback flow of information; the agile supply chain insists upon the improvement of the adoptability and flexibility and is able to respond and react quickly and effectively to the changing markets [9]. The agile supply chain puts aside the traditional linear organizational structure and establishes a group of institutions using network technology. By doing this, the timespan of delivery to the market decreases [6]. The supply chain agility provides a better competitive environment, and hence enables it to react faster and more effectively to the changes of the market and other instabilities. In addition, institution which have agile supply chain processes are more sensitive to the market, have more ability to equalize supply and demand and also are able to reach shorter timespans. Considering the fact that agility in supply chain of the organization influences directly on manufacturing innovative productions, and their delivery to the customers, this conclusion could be drawn that supply chain agility is an essential factor which affects the general competitiveness [7].

Some prominent writers have defined agility as a combination of enablement criteria agility measurement, while the other quantitative methods have proposed based on hierarchical analysis process. Implementing the method is simple and concentrates on the key issues. Nonetheless, the agile supply chain mainly is rooted in integration, customer sensitivity, organization, processes, networks and informational systems. Based on the previous researches, when the evaluators could not acquire an accurate evaluation, linguistic expressions would be employed to assess vague issues. Because of the fact that enabled agility features are "inaccurate" and "vague", agility measurement is considered a subjective method which uses linguistic terms. Agility measurement is considered to be a problem due to its being multi-dimensional and the lack of a certain criterion for measuring agility-related factors. Reference [4] has surveyed the agile abilities in the supply chain. Regarding their survey, it was discerned to be enormously significant that the sensitivity to the customers in today world's operations.

Reference [11] introduces an instrument for agility measurement which measures the required functionality for the agility as well as organization responsibility agility to the market environment. Fuzzy agility index is one of the last attempts in agility measurement [9]. In this method, variables

are graded and their weight is determined and then fuzzy level average is acquired. Different types of employed methods in this research are shown below in Table 1.

Table 1. Employed Methods

Survey Field	Methodology	Resources
Institution Agility	Conditional Rules	[5]
Supply Chain Agility Measurement	Fuzzy Method of the Agility Evaluation	[9]
Agility Evaluation	Fuzzy Logic	[17]
Supply Chain Agility	Fuzzy Association Rules Mining	[18]
Supply Chain Agility	Graph Theory and Matrix Models	[19]

III. Methodology

In this paper the proposed model of [12] is used from the responsibility indexes, flexibility, speed and competency as the main indexes of agility evaluation.

Responsive: The ability to understand the changes and responding to them as quickly as possible in a reflexive and pre-action and recovered way. Reference [13] considers responsible supply chain as "a network of institutions which are able to produce wealth for their stockholders in a competitive environment and respond quickly and effectively in costs to the changing market requirements."

- Competency: The ability to appoint the institutional goals effectively and sufficiently [14].
- Flexibility/Adoptability: The ability to implement different processes and employing various facilitations to accomplish a goal [15].
- Speed: The ability of finalizing an activity in shortest possible time [8] [16] [17].

A. Using Fuzzy Approach to Quantify the Sub-indexes

For measuring sub-indexes, two questionnaires have been used, one for environment agility weight evaluation and another for measuring supply chain agility indexes. Questionnaires, personal and in interview-questionnaire has accumulated the opinions of company's supply chain managers [20].

B. Variables and Linguistic Terms

In current research, based on [21] and considering a way which concentrate on different humans, a seven-based fuzzy spectrum has used for rating the condition and determining the level of importance (Table 2).

Table 2. Linguistic Terms and Fuzzy Number Related to Each

Linguistic Terms (Importance) (xj, yj, zj)	Fuzzy Number	Linguistic Term (Company Condition)	Fuzzy Number
Very Low	(0, 0.05, 0.15)	Worst	(0, 0.05, 0.15)
Low	(0.1, 0.2, 0.3)	Very Bad	(0.1, 0.2, 0.3)
Middle Low	(0.2, 0.35, 0.5)	Bad	(0.2, 0.35, 0.5)
Middle	(0.3, 0.5, 0.7)	Normal	(0.3, 0.5, 0.7)
Middle High	(0.5, 0.65, 0.8)	Good	(0.5, 0.65, 0.8)
High	(0.7, 0.8, 0.9)	Very Good	(0.7, 0.8, 0.9)
Very High	(0.85, 0.95, 1)	Best	(0.85, 0.95, 1)

IV. Experts Opinions Consensus

There many models which could be used to integrate evaluations of decision makers, including arithmetic average, median and mode. Due to the fact that average operator has been used more than the other methods, in this research the arithmetic operator is used to integrate critics' opinions. If a committee comprised of m evaluator Et, includes t=1,2,…,m, F_j considered factors for evaluating agility, Rtj= (a_{jt}, b_{jt}, c_{jt}) fuzzy numbers suitable to related linguistic rates by critic Et and W_{tj}=(x_{jt},y_{jt},z_{jt}) fuzzy numbers related to the weights of linguistic significance is allocated to F_t by

evaluator E_t. Therefore, the average fuzzy evaluation R_j and balanced fuzzy weight W_j, or the integration of critics' opinions is calculated using equations (1) and (2).

$$Rj = (aj, bj, cj) = (Rj1(+)Rj2(+) \dots (+)Rjm)/m \quad (1)$$

$$Wj = (xj, yj, zj) = (Wj1(+)\, Wj2(+) \dots (+)Wjm)/m \quad (2)$$

The acquired index in this stage, is an informational combination which combines together the rating and fuzzy weights for all factors. The increase in this index causes the main index increase. Therefore, function membership which is determined for this condition, is the indicator of the level of the main index. If W_j and R_j be respectively indicators between fuzzy rank and given fuzzy weight average to the factor j by committee, the whole index is defined as equation (3) [22]:

$$FXI = \sum_{j=1}^{n}(Wj \times Rj)/\ \sum_{j=1}^{n} Wj \quad (3)$$

(Instead of X the value which is measured, is placed, for instance in case of flexibility measurement, F takes the place of X, hence FXI becomes FFI or fuzzy index of flexibility).

1. Adjusting Fuzzy Ranking To Its Suitable Linguistic Level

After computing FXI, the acquired index must be adjusted to its relevant linguistic level. In this stage, the linguistic level is either equal to FXI itself and has full compatibility or the closest level to it. In this research measure the Euclidean distance of a fuzzy number from another fuzzy number. If XL be the indicator of index level X in natural language, then U_{FXI} and U_{Xli} respectively, are indicators of FXI fuzzy function and natural language index i. The distance between U_{FXI} and U_{Xli} are calculated as equation (4) [9]:

$$d(FXI, XLi) = \left\{\sum_{x\epsilon p}\left(UFXI(x) - UXLi\,(x)\right)^2\right\}^{1/2} \quad (4)$$

2. Converting Fuzzy Numbers to Absolute Values

Because of the fact that for calculating matrix constant value there is a need of absolute number, after adjusting each branch to fuzzy values and finding Euclidean distance and applying linguistic level, they must be converted into absolute numbers. In fuzzy literature, for completing this, there are several methods proposed, including center of mass, minimum average, least maximum and etc [9]. In this research the right-left ranking type is used [23]; in this method for acquiring the absolute number it is necessary that fuzzy sets be compared with fuzzy maximum set (max fuzzy) and fuzzy minimum set (min fuzzy) [22]. These two sets are defined (5) and (6).

$$\mu max(x) = \begin{cases} x, 0 \le x \le 1 \\ 0, \text{otherwise} \end{cases} \quad (5)$$

$$\mu max(x) = \begin{cases} 1 - x, 0 \le x \le 1 \\ 0, \text{otherwise} \end{cases} \quad (6)$$

Right-side ranking returns to fuzzy set's intersection or max fuzzy. Right ranking M could be calculated as (7).

$$\mu R(M) = \sup[\mu M(x) \wedge \mu max(x)] \quad (7)$$

Similar to this, left ranking M is calculated by (8).

$$\mu L(M) = \sup[\mu M(x) \wedge \mu min(x)] \quad (8)$$

By acquiring left and right values of M final number is achieved.

$$\mu T(M) = \frac{[\mu R(M) + 1 - \mu L(M)]}{2} \quad (9)$$

V. Conclusion

Regarding the swift changes happening in the world markets [24], it is clear that only the organizations which use agile supply chain could lead the market. The more the environment is agile the higher level of agility in chain must be expected. In order to become and agile supply chain first one should be able to measure the agility so that one could enhance the agility. Researches show that using agile supply chain in the organizations causes the amount of production and simultaneous enhancement of goals like cost, quality, flexibility, delivery and customer services. All of these items individually foster more competitiveness. An analysis of the results of this research shows interesting points, including the difference among companies in agility. "More agile" company has customer-oriented characteristics and employing soft and hard methods to adopt to the changing conditions. They also consider it necessary for the supplier to participate in the process of achieving the highest customers' satisfaction. Also, such conclusion could be drawn that "more agile" companies uses (internet) technology for enhancing the quality of exploitation, developing new product and customer's satisfaction. Respectively, the characteristics of the companies which are less agile might be like this:

These companies are internally concentrated and are biased to their internal operational consequences. They find no connection between customers' satisfaction and the technology. The role of suppliers in these companies is to provide products so that highest benefit is gained.

Regarding the sub-indexes value in discussed supply chain, such conclusion could be drawn that, by the point of view of strategic planning, sensitivity and virtuality, this supply chain has relatively top abilities. This happens while all the sub-indexes of supply chain agility are relatively on top level of spectrum. Considering the fact that all indexes have effect on each other and in all conditions except competency-responsibility have equal and alternative effect on each other, such conclusion could be drawn that a supply chain to gain agility needs improvement in each sub-index, and also due to the fact that the amount of effectivity of the speed and flexibility on other indexes is more, on these two indexes there must be a special attention. Since the agility of this supply chain is determined average, still because the environment agility is the same level, a conclusion could be drawn that the abilities of this supply chain could overcome the changes in the environment. Nevertheless, the companies abilities in current time and environment is responsible as effectively and sufficiently, nonetheless, more agility in supply chain could indirectly affect the reduction of delivery timespan, increase in customer satisfaction and reduction of depositories. Therefore, the following recommendations for increasing this chain agility are proposed:

Since speed and flexibility are considered as the most important factors of agility in this chain, it is suggested that some mechanisms to increase these two indexes be regarded. Using virtual communications is one of the effective factors on both of these indexes which also affect responsibility itself. In fact, one of the highly significant factors related to supply chain agility, is sharing the information alongside the chain. The supply chain's members accessibility (suppliers, producers, distributors and even customers) to the internet, the availability of the internal information networks (internet) accessibility for the supply chain's members, updating the information of the sales, increasing search functionality, exchanging without paper consumption, using web-based software and inter-organizational data-exchange are factors which could affect it and cause the increase in speed in one hand, and on the other hand a better responsibility to the demand. About the flexibility of the resource, the company should be able to supply the market with new and different products within the shortest possible time, and also increase its ability in producing customized product. The company, also, must be able to postpone the production of a product which needs an informational flow alongside the supply chain and on the other hand craves the cooperation of the suppliers extensively. The ability of using modular designing, the other affecting factor on this part, is employing techniques, by using which, versatile materials and segments are employed in order to reach diverse products for satisfying the needs of customers. Competency index and specially sub-index of common culture and decision-making is on lower level than the other indexes, hence it is suggested that a proper ground, for establishing a common culture among the members and building mechanisms for common

decision-making, be thought. The existence of cooperative spirit and participation in policies, programs and executing operation on one hand and fostering risk-taking culture in conjunction with encouraging the chain's members' reliance on the other hand, provide the required atmosphere for common decision-making and common insight among the members. In such condition identifying the customer's needs and attempting to supply his needs and gain his satisfaction together with establishing progressive relations are the main line of viewpoint and activities of supply chain's members.

References

[1] Yusuf Y Y, Gunasekaran A, Adeleye E O, Sivayoganathan K.(2004); "Agile Supply Chain Capabilities: Determinants of Competitive Objectives", *European Journal of Operational Research*, 159, PP. 379–392.

[2] Lambert DM, Cooper M C. (2000); "Issues in Supply Chain Management", *Industrial Marketing Management*, pp. 65–83.

[3] Zhang Z, Sharifi H. (2000); "A Methodology for Achieving Agility in Manufacturing Organizations", *International Journal of Operations & Production Management*, Vol. 20 No. 4, pp. 496-512.

[4] Van Hoek R I, Harrison A, Christopher M (2001);" Measuring Agile Capabilities in the Supply Chain", *International Journal of Operations & Production Management*, Vol. 21 No. 1/2, pp. 126-147.

[5] Tsourveloudis N C, Valavanis K P. (2002); "On the Measurement of Enterprise Agility", *Journal of Intelligent and Robotic Systems*, 33: 329– 342, 2002.

[6] Lou P, Zhou Z, Chen Y.P, Ai W.(2004); "Study on Multi-Agent-Based Agile Supply Chain Management", *International Journal of Advanced Manufacturing Technology*, pp. 23: 197–203.

[7] Swafford P.M, Ghosh .S, Murthy .N (2006); "The Antecedents of Supply Chain Agility of a Firm: Scale Development and Model Testing", *Journal of Operations Management*, 24, pp.170–188.

[8] Christopher M. (2000); "The Agile Supply Chain Competing in Volatile Markets", *Industrial Marketing Management*, 29, pp. 37–44.

[9] Lin CT., Chiu H., Chu P Y. (2006a); "Agility Index in the Supply Chain", *International Journal of Production Economics*, 100, pp. 285–299.

[10] Baker, P. (2008); "The Design and Operation of Distribution Centres Within Agile Supply Chains", *International Journal of Production Economics*, 111(1), pp. 27-41.

[11] Weber M M. (2002); "Measuring Supply Chain Agility in the Virtual Organization", *International Journal of Physical Distribution & Logistics Management*, Vol.32 No.7, PP.577-590.

[12] Ismail H.S, Sharifi H (2006); "A balanced approach to building agile supply chains", *International Journal of Physical Distribution & Logistics Management*, Vol. 36 No. 6, pp. 431-444.

[13] Gunasekaran A.,Lai K.H., Edwin Cheng T.C.,(2008); "Responsive Supply Chain: A Competitive Strategy in a Networked Economy", *Omega* 36, pp: 549 – 564.

[14] Spekman R.E., Spear J., Kamauff J.(2002); "Supply Chain Competency: Learning as a Key Component", *Supply Chain Management: An International Journal*, Vol 7 No 1, pp:41-55.

[15] Duclos L.K., Vokurka R.J., Lummus R.R., (2003); "A Conceptual Model of Supply Chain Flexibility", *Industrial Management & Data System*, Vol 103 No 6, pp. 446-456.

[16] Sharp, J.M., Irani, Z., Desai, S., (1999); Working Towards Agile Manufacturing in the UK Industry, *International Journal of Production Economics*, 62, pp. 155–169.

[17] Lin CT., Chiu H., Tseng Y.H., (2006b); "Agility Evaluation Using Fuzzy Logic", *International Journal of Production Economics*, 101, pp. 353- 368.

[18] Jain V, Benyoucef L, Deshmukh S.G.(2007); "A New Approach for Evaluating Agility in Supply Chains Using Fuzzy Association RulesMining", *International Journal of Engineering Applications of Artificial Intelligence*, In Press - Available online, 2007.

[19] Faisal MN., Banwet DK., Shankar R.(2007); "Quantification of Risk Mitigation Environment of Supply Chains Using Graph Theory and Matrix Methods", European J. *Industrial Engineering*, Vol. 1, No. 1, pp. 29-39.

[20] Sharifi, H., Zhang, Z., (2000); "A Methodology for Achieving Agility in Manufacturing Organization: An Introduction"; *International Journal of Production Economics*, 62, 7–22.

[21] Yang, S.L., Li, T.F., (2002); Agility Evaluation of Mass Customization Product Manufacturing, *Journal of Materials Processing Technology*, 129, pp. 640–644.

[22] Liu H., Kong F., (2005); "A New Madm Algorithm Based On Fuzzy Subjective and Objective Integrated Weights", *International Journal of Information and Systems Sciences Computing and Information*, Volume 1, Number 3-4, pp: 420–427

[23] Chen, C.T., Peng, S.T., (1999); "Intelligent Process Control Using Neural Fuzzy Techniques", *Journal of Process Control*, 9, pp. 493–503.

[24] Karimimalayer M, Faieza A.A, Bagherpour E, Movahedizadeh H , SamimiSedeh N, (2014). A Comparison of Quality Management and Industrial Criteria between Iran and Developed Countries (Case Study: Japan). *Research Journal of Applied Sciences, Engineering and Technology*, 7(20): 4359-4363.