Design and development of supply chain agility assessment model by fuzzy logic

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ABSTRACT

Supply Chain Management is an essential constituent of Agile manufacturing (AM). Contemporary supply chains have acquired agile attributes such as volatile market demand, high product variety, high profit margin, short product life cycle etc. The quantification of supply chain agility gains extreme importance as it indicates the strategic agile position of an organization from supply chain perspective Fuzzy logic approach has been used to compute supply chain agility. The case study has been carried out in a manufacturing organization situated in Tiruchirappalli. The output of the case study includes the computation of supply chain agility index and fuzzy performance important index of various supply chain agile attributes.

Keywords - Agile Manufacturing, Supply Chain Management; Agility Index, Fuzzy Logic.

INTRODUCTION

The increasing competition has been forcing the manufacturing organizations to develop various manufacturing paradigms for satisfying the requirements of the customers (Cater et al. 2005). The demand conditions of markets are fluctuating due to varied customers' requirements. This situation has marked the emergence of a new manufacturing paradigm called Agile Manufacturing (AM) (Gunasekaran, A, et al. 2008). AM enables an organization to produce a variety of products within a short period of time in a cost effective manner. Supply chain management (SCM) is one of the managerial enablers of AM. The contemporary supply chains have acquired agile attributes such as high product variety, high profit margin and short product life cycle. In this context, the quantification of supply chain agility gains importance as it is an indicator of strategic agile position of an organization from supply chain perspective. This project is concerned with the assessment of supply chain agility of manufacturing organization using fuzzy logic approach (Lin et al 2006). The current characteristics of agile supply chains currently prevailing at XYZ have been studied. After the identification of supply chain agility, the importance index of various agile supply chain attributes has been determined. This is followed by the derivation of various proposals for improvement of supply chain agility of the organization.

LITERATURE REVIEW

Iskanius (2006) has mentioned virtual enterprise/ organization, outsourcing, collaborative relationships, Production planning, Product design & service, Customer focus, Customer and market sensitivity as the characteristics of agile supply chain. In this study, the case network has been undergoing a shift towards project-oriented business, where quick responses are the priority and agility is recognized as the facilitating factor. Using a constructive approach, an agile supply chain for a steel product network, Steel Net system, is developed. In this study, qualitative methods such as interviews, observations, questionnaires and documents are used as data collection methods. Christopher et al (1998) have discussed about Market sensitivity, Process integration, Networking and Cycle time reduction as the characteristics of agile supply chain and has successfully delivered a wide range of products to those markets where cost is the primary order winning criteria. This has led to the emergence of the agile paradigm characterized by 'quick response' and similar initiatives. Chopra et al (2007) have explained aspects related to inventory management, supplier relationship management, enterprise wide relationship management, supply chain partner selection and internal supply chain management as the characteristics of agile supply chain. Paneerselvam (2002) has mentioned time management and nature of management as the characteristics of agile supply chain.

Lou et al (2004) have defined agile supply chain as a network from the topologic structure which is composed of autonomous or semi-autonomous enterprises. All enterprises work together for procurement, production and delivery. An important factor to the agility in manufacturing enterprises is flexibility among firms so that they can react to changes effectively, driven by customer designed products and production capacity to rapid new product launch. Canidar (2007) observed issues related to inventory management cost, warehousing, materials handling cost, transportation management cost, supply/demand planning cost and sourcing/procurement Processes (Excluding Purchases of Goods Cost). Christopher et al (1998) has defined agile supply chain and discussed about the characteristics of volatile markets. Volatile markets mean the supply chain is capable of reading and responding to real demand. One of the keys to achieve agile response to fast-changing markets lies upstream of the organization in the quality of supplier relationships. Often it is the lead-time of in-bound suppliers that limits the ability of a manufacturer to respond rapidly to customer requirements. Equally new product introduction time can be dramatically reduced through the involvement of suppliers in the innovation process. Waddington (2002) has mentioned the design aspects of agile supply chain; Supply chain management is moving away from traditional processes to agile capability to realize operations on actual demand, where information is instantly available through information sharing and exchange and organizations are designed for maximum efficiency during the integration processes. Viharos et al (2006) have discussed about the integration of the production, quality and process monitoring for enabling agile manufacturing. In this paper, a parametric manufacturing knowledge representation model was proposed to address the issue of product configuration variation and manufacturing agility to facilitate agile manufacturing. Variation product configuration (VPC) model has been proposed for modeling of manufacturing facility and process, respectively. The concepts of manufacturing capability for facility and process, as well as the mechanism for matching them, were also introduced in the proposed model. With these models, the knowledge of manufacturing facility and process for products with wide variations can be concisely represented for agile manufacturing.

Lin et al (2006) have utilized fuzzy logic approach for assessing supply chain agility of manufacturing organization. They have mentioned that a supply chain must possess a number of distinguishing enable-attributes such as distribution networks, Manufacturing capabilities, Interchange-ability of personnel and Learning organization, Yusuf et al (2003). Due to the qualitative and ambiguous attributes linked to agility assessment, most measures are described subjectively using linguistic terms, and cannot be handled effectively using conventional assessment approaches. However, fuzzy logic provides an effective means of dealing with problems involving imprecise and vague phenomena. The survey aims to understand the information that will be considered in assessing agility-enabler-attributes. Assessments thus are frequently measured linguistically rather than numerically. Many methods can be adopted to aggregate the assessments of multiple decision-makers, such as arithmetic mean, median, and mode. Since the average operation is the most widespread aggregation method, this study uses the arithmetic mean to pool the opinions of experts.

Elmuti et al (2008) posits the longitudinal approach for assessment of supply chain agility. The purpose of this article is to investigate the impact of integrated supply chain management on productivity, efficiency, and performance of participants in the system, in an industrial field. Actual organizational data from the survey firm was used. Follow-up interviews were conducted with key managers in the manufacturing facility. The results show positive and substantial improvements in overall performance as a result of integration and coordination of the internal functions within the firm and effectively linking them with their external suppliers. The results also support the claims that an integrated supply chain involves aligning outsourcing activities to achieve the organizational goal of responding positively to the needs of consumers. Several factors were identified as key contributors to supply chain program success in this firm. These included sharing information through new technologies, established partnerships with key suppliers, and constant communication with employees. This exploratory empirical study provides insight into the effectiveness of implementing an integrated supply chain management approach for increasing the probability of success in the supply chain management approach and identifies areas that need further investigation.

RESEARCH METHODOLOGY

Selection of a manufacturing organization for conducting case study
Assessment of performance ratings and weights of agile supply chain attributes using linguistic terms
Determination of importance index of various agile supply chain attributes
Identification of the proposals for supply chain agility improvement
Approximation of linguistic terms by fuzzy numbers
Literature review on supply chain agility evaluation
Development of a conceptual model for supply chain agility evaluation
Determination of the supply chain agility index of the organization

The methodology followed during this project is shown Fig. 1.The project begins with the literature review on the evaluation of supply chain agility. Then, a conceptual model for supply chain agility evaluation has been developed. This is followed by the selection of a manufacturing organization for conducting the case study. The performance rating and weights of agile supply chain attributes are assessed using linguistic terms. This is followed by the approximation of linguistic terms by fuzzy numbers. Then, the supply chain agility index of

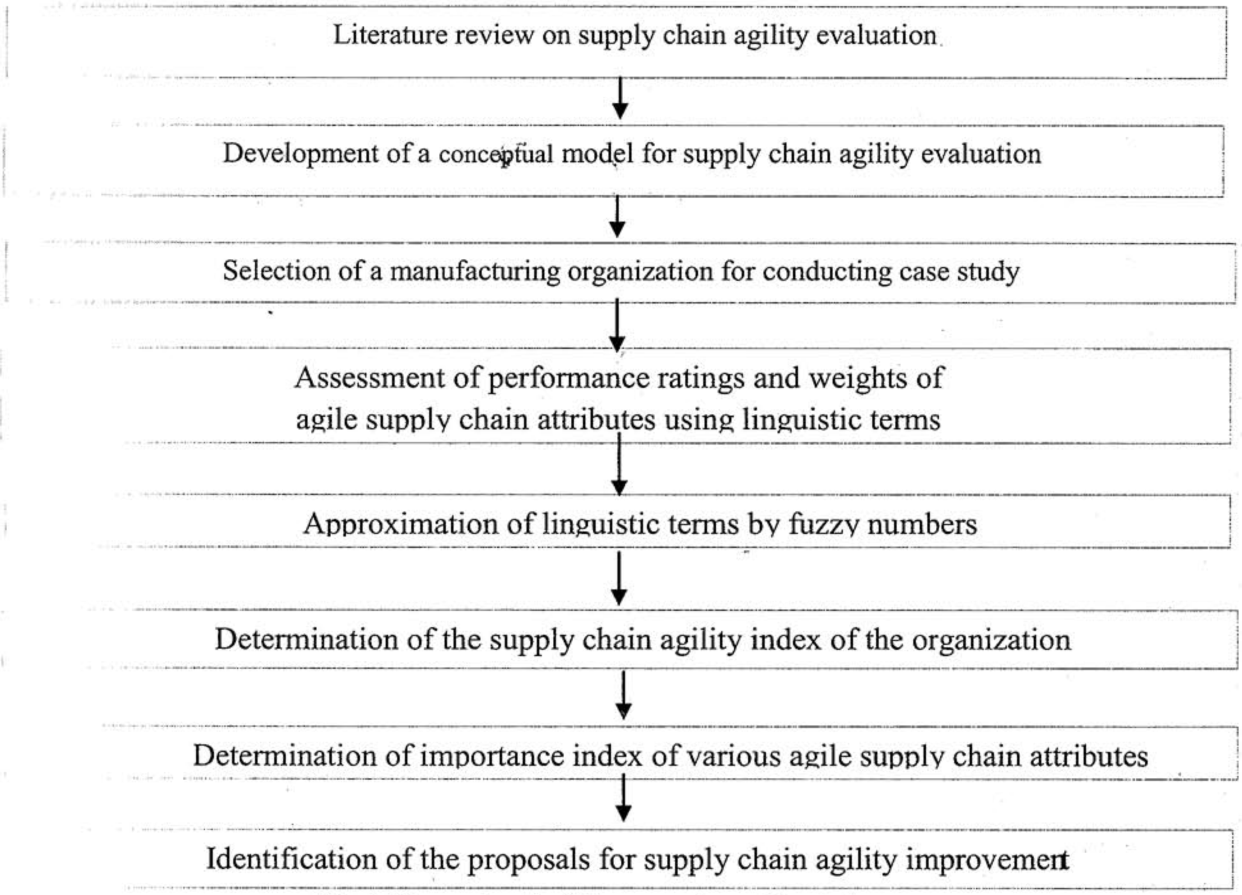

Fig.1 Flow chart of Research methodology

the organization has been determined. Then, the importance index of various agile supply chain attributes has been found. Then, the proposals have been derived for supply chain agility improvement.

CONCEPTUAL MODEL FOR SUPPLY CHAIN AGILITY EVALUATION

The conceptual model for supply chain agility evaluation has been shown in Table 1. The model consists of 5 agile supply chain enablers, 20 agile supply chain criteria and 86 agile supply chain attributes. The model is comprehensive as it has been developed from literature by referring to various peer reviewed journal papers. Agile Supply Chain enablers present the first level, agile supply chain criteria formed the second level and Agile Supply Chain attributes formed the third level.

DETERMINATION OF APPROXIMATE LINGUISTIC TERMS FOR ASSESSING PERFORMANCE RATING AND IMPORTANT WEIGHTS OF AGILE ATTRIBUTES

The linguistic terms are used to assess the performance rating and important weights of agile attributes. In order to assist in assigning the performance rating of agile attributes, the linguistic variables (Excellent (E), Very Good (VG), Good (G), Fair (F), Poor (P), Very Poor (VP) and Worst (W)) are used. In order to assess the importance weights of agile attributes, the linguistic variables (Very High (VH), High (H), Fairly High (FH), Medium (M), Fairly Low (FL), Low (L), and Very Low (VL)) are used. The linguistic variables and fuzzy numbers used in this paper are shown in Table 2.

Table 1: Supply chain agility evaluation model

S. No	Enablers	Criteria	Attributes
2	Collaborative relationships	Enterprise wide relationship management	Concurrent relationship of supply chain activities
			Focus on core competencies
			Team based on goal setting
			Active data sharing with partners
			Interlinking of departments
		Supplier relationship management	Formation of strategic alliances
			Trust and competency of the suppliers
			Design and supply collaboration modalities/system
			Negotiation
			Networking of partners

Table 2: Linguistic variables and fuzzy number used

Linguistic variable	Fuzzy number	Linguistic variable	Fuzzy number
Worst (W)	(0, 0.5, 1.5)	Very Low (VL)	(0, 0.05, 0.15)
Very Poor (VP)	(1, 2, 3)	Low (L)	(0.1, 0.2, 0.3)
Poor (P)	(2, 3.5, 5)	Fairly Low (FL)	(0.2, 0.35, 0.5)
Fair (F)	(3, 5, 7)	Medium (M)	(0.3, 0.5, 0.7)
Good (G)	(5, 6.5, 8)	Fairly High (FH)	(0.5, 0.65, 0.8)
Very Good (VG)	(7, 8, 9)	High (H)	(0.7, 0.8, 0.9)
Excellent (E)	(8.5, 9.5, 10)	Very High (VH)	(0.85, 0.95, 1.0)

Table 3: Linguistic variables of Performance Rating provided by experts

Serial Number	Enablers	Criteria	Attributes	E_1	E_2	E_3	E_4	E_5	E_6
2	$ASCE_2$	$ASCC_6$	$ASCA_{61}$	H	FH	FH	FH	H	H
			$ASCA_{62}$	H	M	FH	FH	H	VH
			$ASCA_{63}$	H	FH	H	FH	H	H
			$ASCA_{64}$	H	M	FH	FH	H	FH
			$ASCA_{65}$	VH	M	H	H	VH	FH
			$ASCA_{66}$	FH	FH	FH	H	H	H
		$ASCC_7$	$ASCA_{71}$	H	FH	M	H	VH	H
			$ASCA_{72}$	VH	FH	M	FH	H	H
			$ASCA_{73}$	H	FH	FH	VH	VH	VH
			$ASCA_{74}$	FH	FH	FH	H	VH	M

Table 4: Linguistic variables of Importance Weights provided by experts

Serial Number	Enablers	Criteria	Attributes	E_1	E_2	E_3	E_4	E_5	E_6
2	$ASCE_2$	$ASCC_6$	$ASCA_{61}$	F	G	G	G	G	F
			$ASCA_{62}$	G	F	G	G	G	G
			$ASCA_{63}$	F	G	VG	G	VG	F
			$ASCA_{64}$	G	F	G	G	G	F
			$ASCA_{65}$	F	F	VG	G	VG	F
			$ASCA_{66}$	F	G	G	G	G	F
		$ASCC_7$	$ASCA_{71}$	G	G	G	G	G	F
			$ASCA_{72}$	F	G	F	F	G	VG
			$ASCA_{73}$	G	G	G	G	VG	G
			$ASCA_{74}$	F	G	G	F	G	F

MEASUREMENT OF PERFORMANCE RATINGS AND IMPORTANCE WEIGHTS OF AGILE SUPPLY CHAIN ATTRIBUTES USING LINGUISTIC TERMS

The linguistic variables for assessing the performance ratings, importance weights are gathered from 7 executives of XYZ and are shown in Table 3 and Table 4.

AGGREGATION OF FUZZY RATING AND FUZZY WEIGHTS OF AGILE SUPPLY CHAIN

The average fuzzy ratings is given by R_j and average performance weights is given by W_j

$$R_j = (a_j, b_j, c_j) = (R_{j1}(+)R_{j2}(+)......(+)R_{jm})/m \quad (1)$$

$$W_j = (x_j, y_j, z_j) = (W_{j1}(+)W_{j2}(+)W_{jm})/m \quad (2)$$

Consolidated fuzzy rating and fuzzy weights are used to determine the supply chain agility level.

Fuzzy Agility Index (FAI)

$$\text{FAI} = \sum_{j=1}^{n} \left(W_j (\cdot) R_j \right) \Big/ \sum_{j=1}^{n} W_j \qquad (3)$$

As a sample, the average fuzzy rating and average fuzzy weight of Agile Supply Chain attribute "Incorporation of IT utilities in SCM" has been shown as follows.

$ASCA_{11}$ = [G+ F+VG+F+G+G+E] / 7 from equation (1)

[(5, 6.5, 8) + (3, 5, 7) + (7, 8, 9) + (3, 5, 7) + (5, 6.5, 8) + (5, 6.5, 8) + (8.5, 9.5, 10)] / 7

$ASCA_{11}$ = (7.71, 6.71, 8.14)

$ASCA_{12}$ = [F + G + F+ G +F + F+G] / 7

[(3, 5,7) + (5, 6.5, 8) + (3,5,7) + (5, 6.5, 8) + (3, 5 ,7) + (3, 5 ,7)+ (7,8,9)] / 7

$ASCA_{12}$= (6.71, 5.64, 7.43)

$ASCA_{13}$= [F + G + P + G + G +G+E]/ 7

[(3, 5, and 7) + (5, 6.5, 8) + (2, 3.5, 5) + (5, 6.5, 8) + (5, 6.5, 8) + (5, 6.5, 8) + (8.5, 9.5, 10)] / 7

$ASCA_{13}$= (7.29, 6.29, 7.71)

$ASCA_{11}$ = [H + M + H + VH + H + M+FH] / 7 from equation (2)

$ASCA_{11}$= (0.58, 0.714, 0.843)

$ASCA_{12}$ = [H + FH + M + FH + H + H+FH] / 7

$ASCA_{12}$= (0.56, 0.693, 0.829)

$ASCA_{13}$= [FH + FH + FL + FH + H + H+H] / 7

$ASCA_{13}$= (0.54, 0.671, 0.80)

The aggregated fuzzy ratings and fuzzy weights of main and sub criteria are presented in Table 5.

TABLE 5: AVERAGE FUZZY RATING AND AVERAGE FUZZY WEIGHTS

Attributes	Fuzzy average ratings	Fuzzy average weights
$ASCA_{61}$	(4.33, 6.00, 7.66)	(0.60, 0.725, 0.85)
$ASCA_{62}$	(4.66, 6.25, 7.83)	(0.608, 0.725, 0.85)
$ASCA_{63}$	(5.00, 6.50, 8.00)	(0.633, 0.75, 0.867)
$ASCA_{64}$	(4.33, 6.00, 7.66)	(0.533, 0.675, 0.817)
$ASCA_{65}$	(4.66, 6.25, 7.83)	(0.65, 0.775, 0.883)
$ASCA_{66}$	(4.33, 6.00, 7.66)	(0.6, 0.725, 0.85)
$ASCA_{71}$	(4.66, 6.25, 7.83)	(0.625, 0.75, 0.867)
$ASCA_{72}$	(4.33, 6.00, 7.66)	(0.592, 0.725, 0.85)
$ASCA_{73}$	(5.33, 6.75, 8.16)	(0.708, 0.825, 0.917)
$ASCA_{74}$	(4.00, 5.75, 7.50)	(0.558, 0.7, 0.833)

As a sample, the average fuzzy rating of Agile Supply Chain attribute "Incorporation of IT utilities in SCM" has been shown as follows.

$ASCA_{11}$ = [G+ F+VG+F+G+G] / 6

[(5 , 6.5 , 8) + (3,5,7) + (7 , 8, 9) + (3, 5 ,7) + (5, 6.5, 8) + (5, 6.5, 8)] / 6

$ASCA_{11}$ = (4.66, 6.25, 7.83)

$ASCA_{12}$ = [F + G + F+ G +F + F] / 6

[(3, 5,7) + (5, 6.5, 8) + (3,5,7) + (5, 6.5, 8) + (3, 5 ,7) + (3, 5 ,7)] / 6

$ASCA_{12}$= (3.66, 5.5, 7.33)

$ASCA_{13}$= [F + G + P + G + G +G]/ 6

[(3, 5, and 7) + (5, 6.5, 8) + (2, 3.5, 5) + (5, 6.5, 8) + (5, 6.5, 8) + (5, 6.5, 8)] / 6

$ASCA_{13}$= (4.16, 5.75, 7.33)

The integrated fuzzy ratings of main criteria outsourcing has been calculated as

$ASCA_1$=[(4.66 ,6.25 , 7.83) (*) (0.59, 0.72 ,0.85) +(3.66, 5.5 , 7.33)(*)(0.56, 0.7 , 0.83) + (4.16, 5.75, 7.33)(*)(0.51, 0.65 , 0.78)] / [(0.59 , 0.72 , 0.85) + (0.56 , 0.7 , 0.83)+ (0.51 , 0.65 , 0.78)]

$ASCA_1$= (4.15, 5.83, 7.49)

Other integrated fuzzy ratings are obtained in a similar manner. After applying the equation (3), the fuzzy agility index (FAI) is found as (FAI) = (4.685, 6.221, 7.745)

DETERMINATION OF EUCLIDEAN DISTANCE TO MATCH FAI WITH APPROXIMATE AGILITY LEVEL

Once the FAI has been obtained, it can be matched with linguistic level. Euclidean distance method is the most widely used method for matching the membership function with linguistic term. In our paper, the agility level (AL) has been set as (Extremely Agile [EA], Very Agile [VA], Agile [A], Fairly [F], Slowly [S]) has been selected for labeling. Euclidean distance has been used to find the distance between FAI and AL.

- Extremely Agile [EA]=(7,8.5,10)
- Very Agile [VA]=(5.5,7,8.5)
- Agile [A]=(3.5,5,6.5)
- Fairly [F]=(1.5,3,4.5)
- Slowly [S]=(0,1.5,3)

The membership function used for calculating FAI is given by,

$$f_A(x)=\begin{cases}(x-a)/(b-a), & a\le x\le b,\\ (x-c)/(c-b), & b\le x\le c,\\ 0, & otherwise\end{cases} \quad (4)$$

For FAI

$$f_A(x)=\begin{cases}(x-6.41)/0.92, & 6.41\le x\le 7.33,\\ (x-7.89)/0.56, & 7.33\le x\le 7.89,\\ 0, & otherwise\end{cases} \quad (5)$$

$$d(FAI, AL_i)=\left\{\sum_{x\in p}\left(f_{FAI}(x)-f_{AL_i}(x)\right)^2\right\}^{1/2} \quad (6)$$

D (FAI, EA) = 2.965

D (FAI, VA) = 2.562

D (FAI, A) = 1.963

D (FAI, F) = 2.235

D (FAI, S) = 2.523

By matching a linguistic label with minimum D, the agility level has been identified as "Agile".

IDENTIFICATION OF IMPORTANCE INDEX OF VARIOUS AGILE SUPPLY CHAIN ATTRIBUTES

Agility evaluation procedure must not be stopped with determination of agility Level; it must identify principle obstacles for improvement. FPII (Fuzzy Performance Importance Index), it used to identify the principle obstacles. FPII is calculated as

$$FPII_{ijk} = W'_{ijk} \otimes R_{ijk} \quad (7)$$

where $W'_{ijk} = (1,1,1) - W'_{ijk}$

W'_{ijk} is the fuzzy importance weight of the agility element capability ijk.

A sample calculation of FPII of Agile Supply Chain Attribute 'Incorporation of IT utilities in SCM' has been shown as follows

$FPII_{11} = 2.41$

FPII needs to be ranked using Chen and Hwang and Left- and- Right Fuzzy Ranking method for various Agile Supply Chain Attributes. FPII can be obtained using following equations.

$$f_{max}(x)=\begin{cases}x, & 0\leqslant x\leqslant 10\\ 0, & otherwise\end{cases} \quad (8)$$

$$f_{\min}(x) = \begin{cases} 10 - x, & 0 \leqslant x \leqslant 10 \\ 0, & \text{otherwise} \end{cases} \quad (9)$$

When given a triangular fuzzy number FPII defined as +"$_{FPII}$: R'! [0, 10], with a triangular

Membership function, the right-and-left scores of FPII can be obtained, respectively, as

$$U_R(FPII) = \sup_x [U_{FPII}(x) \wedge U_{\max}(x)] \quad (10)$$

$$U_L(FPII) = \sup_x [U_{FPII}(x) \wedge U_{\min}(x)] \quad (11)$$

Finally, the total score of FPII can be obtained by combining the left-and-right-scores. The total score of FPII is defined as

$$U_T(FPII) = [U_R(FPII) + 10 - U_L(FPII)]/2 \quad (12)$$

Using the total score, the fuzzy numbers can be ranked. For example, the total scoring value of a fuzzy number $FPII_{11}$ (1.053, 2.205, 3.418) is calculated as

Table 6: Fuzzy Performance Importance Index (FPII) of various sub-criteria

Attributes	Fuzzy average ratings	(1.0,1.0,1.0) - W_i	Fuzzy Performance Importance Index
$ASCA_{61}$	(4.33, 6, 7.66)	(0.15, 0.4, 0.275)	(0.6495, 2.4, 2.1065)
$ASCA_{62}$	(4.66, 6.25, 7.83)	(0.15, ,0.392, 0.275)	(0.699, 2.45, 2.15325)
$ASCA_{63}$	(5, 6.5, 8)	(0.133, 0.367, 0.25)	(0.665, 2.3855, 2)
$ASCA_{64}$	(4.33, 6, 7.66)	(0.183, 0.467, 0.325)	(0.79239, 2.802, 2.4895)
$ASCA_{65}$	(4.66, 6.25, 7.83)	(0.117, 0.35, 0.225)	(0.54522, 2.1875, 1.76175)
$ASCA_{66}$	(4.33, 6, 7.66)	(0.15, 0.4, 0.275)	(0.6495, 2.4, 2.1065)
$ASCA_{71}$	(4.66, 6.25, 7.83)	(0.133, 0.375, 0.25)	(0.61978, 2.34375, 1.9575)
$ASCA_{72}$	(4.33, 6, 7.66)	(0.15, 0.408, 0.275)	(0.6495, 2.448, 2.1065)
$ASCA_{73}$	(5.33, 6.75, 8.16)	(0.083, 0.292, 0.175)	(0.44239, 1.971, 1.428)
$ASCA_{74}$	(4, 5.75, 7.5)	(0.167, 0.442, 0.3)	(0.668, 2.5415, 2.25)

$$U_R(FPII) = \sup_x [U_{FPII}(x) \wedge U_{\max}(x)] = 3$$

$$U_L(FPII) = \sup_x [U_{FPII}(x) \wedge U_{\min}(x)] = 8.2$$

$$U_T(FPII) = [U_R(FPII) + 10 - U_L(FPII)]/2 = [3 + 10 - 8.2]/2 = \mathbf{2.41}$$

As above, total score of agile supply chain attribute 'Incorporation of IT utilities in SCM' is found as 2.41. Similarly, scores have been computed for all 86 agile supply chain attributes and are shown in Table 6

DISCUSSION AND CONCLUSION

Agile manufacturing is the contemporary manufacturing strategy which enables the modern organization to survive in the competitive environment. The evaluation of supply chain agility gains vital importance in modern scenario. Fuzzy approach has it focus on linguistic approximation and fuzzy arithmetic agility. The computation of FAI and Euclidean Distance has indicated the organization is 'Agile'. This inference very much coincided with the practical culture prevailing in the organization. This kind of approach enables the organization to identify the strength and weakness to compete in the global scenario.

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