CHAPTER 5

EVALUATION OF AGILITY IN SUPPLY CHAIN

The contemporary manufacturing organizations have realized that agility in their supply chain is quite essential for the survival and competitiveness. In the way of implementing agility in supply chain the issues to be examined are of agility, its measurement, agility level and barriers. One of the research agenda in agile manufacturing is the assessment of agility in supply chain. The assessment of agility in supply chains is quite important as it is an indicator of strategic agile position (Vinodh & Prasanna, 2011). Agility assessment reveals the strategic agile position of an organization in the competitive business environment (Vinodh et al., 2010).

In chapter 4, seven ASC enablers, which act as the driving force at every stage of supply chain, were identified. To facilitate a better understanding of the ASC enablers, an analysis of enablers, inter-relationship, hierarchy of importance and classification were developed. Now coming to the present chapter, a conceptual model is developed, considering the same seven ASC enablers and their attributes, for assessment of agility and identification of obstacles to agility in a supply chain.

The conceptual model is divided into three levels, namely, enablers, attributes and sub-attributes. These enablers, attributes and sub-attributes are called agile capabilities (Vinodh and Devadasan, 2011). Identification of agile capabilities is carried out through the literature review and finalized with the help of experts. The first level consists of seven ASC enablers; the second level consists of 25 ASC attributes; and the third level consists of 101 ASC sub-attributes. After designing this model, a case study was carried out in a manufacturing company situated in North India for validation of the conceptual model. The responses of the experts were gathered for performing an assessment. Based on the

inputs gathered, the Agility Level (AL) of the supply chain of a manufacturing organization has been computed using a fuzzy logic approach. The Fuzzy Logic Approach (FLA) provides a useful tool to deal with problems in which the phenomena are imprecise and vague (Lin et al., 2006b).

Here it is interesting to know that there are eight enablers, 29 attributes and 125 sub-attributes that were identified by literature as agile capabilities. Out of these agile capabilities, one enabler, 4 attributes and 24 sub-attributes had been dropped out from the lists as suggested by the experts. Marketing strategy is considered as eighth enablers for the developing conceptual model for agility evaluation. As per the experts, case-organization is government owned production unit, and they don't give much importance to marketing strategy. It is due to reason that capacity of case-organization is fixed and they have more than sufficient orders from their customers and hence they don't need any kind of marketing strategy. Further they are not working on capacity enhancement. Once marketing strategy is removed from the list, three attributes and 14 sub-attributes related to marketing strategy have been removed automatically.

There is one attribute (*proper distribution and alignment of revenue generated*) of enablers 'collaborative relationship' is not considered as agile capabilities because in order to initiate collaborative relationship between partners, proper distribution and alignment of revenue generated is necessary. Therefore this is not taken as agile capabilities and hence two sub-attributes of aforementioned attribute are automatically removed.

Remaining eight sub-attributes are removed from the lists because some of them do not much effluence the case organization and some of them have more or less similar meaning to others sub-attributes with respect to case-organization and in some case two sub-attributes are combined as one. For example '*elimination of paper work by IT*' is

considered as sub-attributes of '*Use of Information Technology*' but according to experts it is insignificant sub-attributes since it has nothing to do with agility. Sub-attributes '*committed response from partners*' and '*dedication from partners*' contains almost similar meaning hence experts have advised to remove second sub-attributes from the model formulation. Two sub-attributes '*availability of equipment and resources for transportation*' and '*efficiency of equipment used for transportation*' merge in one sub-attribute as '*availability of efficient equipment and resources for transportation*'. There is no any agile capability, which was not reported in literature but finalized by experts.

5.1 Framework for agility evaluation

The framework for the agility evaluation approach followed during this study is shown in Figure 5.1. The first step of this framework is to identify and finalize agile capabilities with the help of a literature survey and experts' opinion. After identification and finalizing agile capabilities, the next step is to develop a conceptual model. Figure 5.2 shows the conceptual model for measuring agility in a supply chain. To evaluate agility, selected experts from the case-organization were required to assign performance ratings and importance weights for agile capabilities. Experts were asked to assess the performance ratings and importance weights for agile capabilities. Linguistic terms were used to assign the ratings and weights. This is followed by the approximation of linguistic terms by fuzzy numbers. Later, the supply chain agility is calculated in the form of an Agility Index (AI). AI is matched with the natural expression linguistic terms using a Euclidean distance method to determine the agility level of the supply chain. Finally, the Fuzzy Performance Importance Index (FPII) is calculated, which helps to identify the barriers within the supply chain.

5.2 Conceptual model for agility evaluation

A conceptual model for agility evaluation in a supply chain is depicted in Figure 5.2. The model is comprehensive and it is developed by referring to the literature related to the assessment of agility in a supply chain. The objective of the model is to evaluate agility in the supply chain. The model is divided into three levels. The first level consists of ASC enablers. Each ASC enablers is divided into ASC attributes in the second level. Finally, each ASC attribute is further divided into ASC sub-attributes in the third level. The present model consists of seven ASC enablers, 25 ASC attributes and 101 ASC sub-attributes. All the ASC enablers, attributes and sub-attributes are listed in Table 5.1.

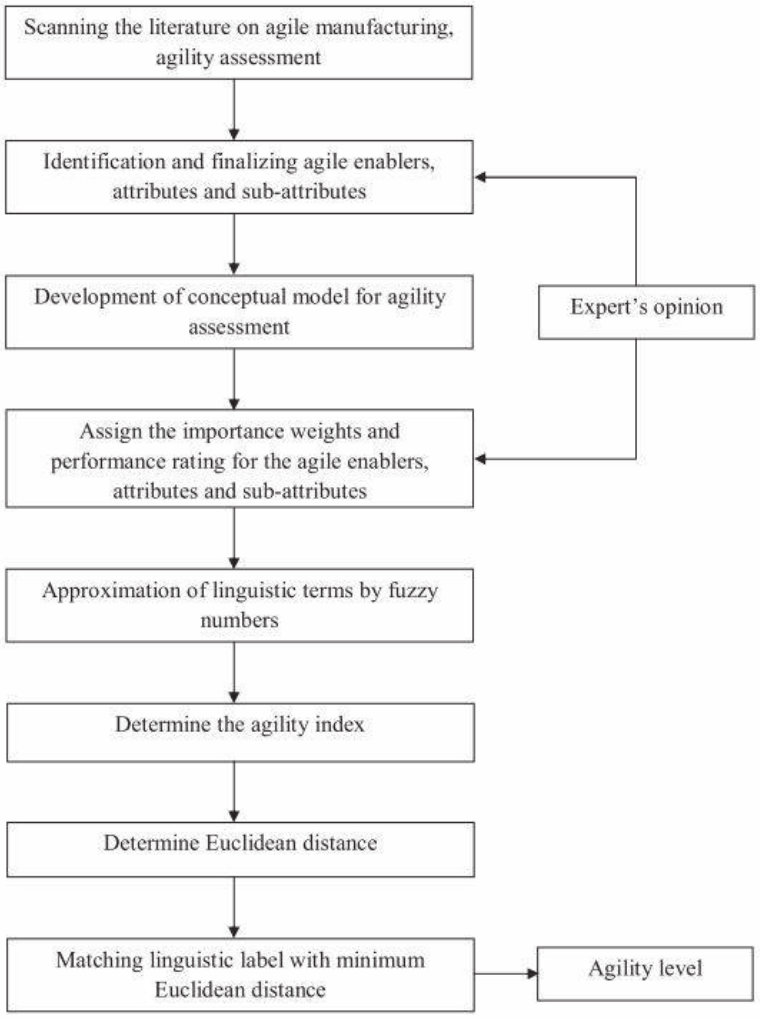

Figure 5.1: Framework for assessment of agility in supply chain

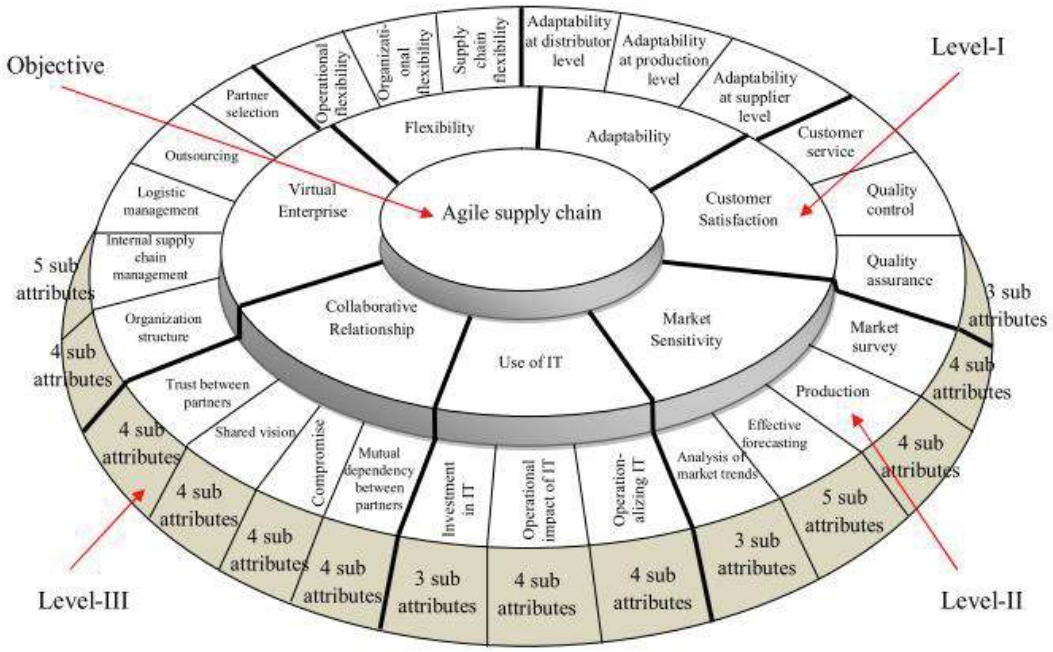

Figure 5.2: Conceptual model for measuring agility in supply chain

5.3 An illustrative example

In this section, the Fuzzy Agility Evaluation Approach (FAEA) is used to study and measure the agility of a supply chain. The case study has been carried out at a North India-based manufacturing organization. The detailed steps of agility evaluation will be presented in the following sections.

Table 5.1: Agility capabilities for agility evaluation in supply chain

S.N.	ASC enablers (E_i)	ASC attributes (A_{ij})	ASC sub-attributes (SA_{ijk})
1	Virtual Enterprise (E_1)	Partner selection (A_{11})	Compatibility of supplier with your company (SA_{111}) Long term relationship potential (SA_{112}) Process and technological capabilities (SA_{113}) Location of supplier (SA_{114}) Partner selection based on quality, service and pricing (SA_{115})
		Outsourcing (A_{12})	Control over outsourced component (SA_{121}) Dependency on outsourcing (SA_{122}) Trust in outsourcing (SA_{123}) Quality of outsourced product (SA_{124})

			Reduced costs (SA_{125})
		Logistic management (A_{13})	Appropriate handling of materials (SA_{131}) Availability of efficient equipment and resources for transportation (SA_{132}) Regularity of services (SA_{133}) Optimized route scheduling (SA_{134})
		Internal Supply Chain Management (A_{14})	Flexibility in order quantity and lead time (SA_{141}) Shipment and delivery accuracy (SA_{142}) Social and environmental responsibility (SA_{143}) Preparation against disruptions (SA_{144}) Assembly line efficiency (SA_{145})
		Organizational structure (A_{15})	Team-oriented decision making (SA_{151}) Interchange-ability of personnel (SA_{152}) Team formation and management (SA_{153}) Capability of Human Resource (SA_{154})
2	Collaborative Relationship (E_2)	Trust between partners (A_{21})	Committed response from partners (SA_{211}) Disturbance handling mechanisms (SA_{212}) Partner's reputation (SA_{213}) Transparency of partners (SA_{214})
		Shared vision (A_{22})	Concurrent relationship of supply chain activities (SA_{221}) Working as team (SA_{222}) Joint product development and launching (SA_{223}) Profit according to financial share (SA_{224})
		Compromise (A_{23})	Supplier involvement in compromise (SA_{231}) Negotiation (SA_{232}) Focus on core competencies (SA_{233}) Information and risk sharing (SA_{234})
		Mutual dependency between partners (A_{24})	Proactive approach (SA_{241}) Networking of partners (SA_{242}) Contractual relationship (SA_{243}) Supporting and encouraging each other (SA_{244})
3	Use of Information Technology (E_3)	Investment in IT (A_{31})	Impact on organization performance (SA_{311}) Decline in IT costs (SA_{312}) Technological advancement in IT (SA_{313})
		Operational impact of IT (A_{32})	Responsiveness of the business process (SA_{321}) Dependability on IT (SA_{322}) Impact on productivity (SA_{323}) High information availability (SA_{324})
		Operationalizing IT (A_{33})	IT driven communication (SA_{331}) Incorporation of RFID technology (SA_{332}) Efficient fund transfer (SA_{333})

			Use of business management software (ERP, SAP etc) (SA_{334})
4	Market Sensitivity (E_4)	Analysis of market trends (A_{41})	Market size (SA_{411}) Government Policies (SA_{412}) Supply and Demand (SA_{413})
		Effective forecasting (A_{42})	Change in price (SA_{421}) Order quantity forecasting (SA_{422}) Lead time forecasting (SA_{423}) Income of consumer (SA_{424}) Reduction in taxes (SA_{425})
		Production (A_{43})	Accessibility and functioning of production equipment and work force (SA_{431}) Minimizing of non-value activities (SA_{432}) Consistently supply of raw materials (SA_{433}) External factors (Like climatic conditions, Political factors etc) (SA_{434})
		Market survey (A_{44})	Samples and Data Collection Procedures (SA_{441}) Preparation of valid questionnaire (SA_{442}) The attitude of the people questioned (SA_{443}) Accuracy of market survey (SA_{444})
5	Customer Satisfaction (E_5)	Quality assurance (A_{51})	Product certification (SA_{511}) Well packaging of product (SA_{512}) Provide product manual (SA_{513})
		Quality control (A_{52})	Quality inspection (SA_{521}) Use of statistical process control chart (SA_{522}) Testing of product (SA_{523}) Continuous monitoring (SA_{524})
		Customer service (A_{53})	Guarantee and warranty of product (SA_{531}) Stay in touch with customer (SA_{532}) Providing necessary support (SA_{533}) Feedback from customer (SA_{534})
6	Adaptability (E_6)	Adaptability at supplier level (A_{61})	Supplier bankruptcy (SA_{611}) Adaptability to supply disruption (SA_{612}) Unexpected change in lead time and order quantity (SA_{613})
		Adaptability at production unit (A_{62})	IT adaptability (SA_{621}) Adaptability of not functioning of machinery and equipment (SA_{622}) Adaptability of labor disputes (SA_{623}) Response time to customer (SA_{624})
		Adaptability at distributor level (A_{63})	Forecasting errors (SA_{631}) Unexpected change in lead time (SA_{632}) Adaptability to trade barrier (SA_{633}) Adaptability to counter degradation of brand reputation (SA_{634})
7	Flexibility	Supply chain	Robustness flexibility (SA_{711})

(E_7)	flexibility (A_{71})	Re-configuration flexibility (SA_{712}) Relationship flexibility (SA_{713}) Logistics flexibility (SA_{714})
	Organizational flexibility (A_{72})	Volume flexibility (SA_{721}) Delivery flexibility (SA_{722}) Production flexibility (SA_{723}) Product modification flexibility (SA_{724})
	Operational flexibility (A_{73})	Process flexibility (SA_{731}) Material handling flexibility (SA_{732}) Labor flexibility (SA_{733}) Automation flexibility (SA_{734}) Machine flexibility (SA_{735})

5.3.1 Linguistic scale for assessing the performance ratings and importance weights of agile capabilities

Assessment of agility in a supply chain is largely dependent on estimation of the experts. There may be ambiguity and impreciseness in human thoughts. To deal with ambiguity and impreciseness of human thoughts, linguistic terms can be used. A linguistic variable is a variable whose values are words or sentences in natural or artificial language (Tseng and Lin, 2011). For example, 'good' and 'high' are linguistic variables. Linguistic expressions are very vague and converting them into a numerical value may prove to be difficult (Vinodh et al., 2013). The field of artificial intelligence offers a solution to face these challenges by offering a 'fuzzy logic' methodology. Therefore, in this study, the concept of a fuzzy logic approach is used to assess the performance rating and importance weights of the agility capabilities. The basic concept of fuzzy set theory is already explained in Chapter 3. According to the concept of fuzzy set theory, to assign the performance ratings and importance weights of agile capabilities, experts have to use linguistic terms. It is almost impractical for experts to directly determine the score of a vague indicator (Lin et al., 2006b). Therefore, in this study, linguistic terms are used to assess the performance ratings and importance weights of agile capabilities. The linguistic terms and the

corresponding fuzzy numbers, which were adopted from previous studies, are already tabulated in Chapter 3 (Table 3.3).

5.3.2 Collection of ASC assessment data

In order to assess the performance ratings and importance weights of agility capabilities, six experts from the case-organization were approached with data sheets. Experts responded in the form of linguistic terms which is converted to fuzzy number. After that simple fuzzy arithmetic operations are employed to synthesize these fuzzy numbers into a unique fuzzy number called Fuzzy Agility Index (FAI). Responses collected from the experts of case-organization are shown in Table 5.2 and Table 5.3. As a sample, the linguistic terms for assessing the performance ratings of agile capabilities titled 'virtual enterprise' are tabulated in Table 5.2. Similarly, importance weights for agile capabilities titled 'virtual enterprise' are tabulated in Table 5.3. Performance ratings and importance weights of remaining agile capabilities are tabulated in Appendix A and Appendix B respectively (Appendix sections are at the end of this dissertation). The following notations were used for gathering the data.

R_{ijk} = Performance rating for ASC sub-attribute *ijk*
W_{ijk} = Importance weight for ASC sub-attribute *ijk*
W_{ij} = Importance weight for ASC attribute *ij*
W_i = Importance weight for enabler *i*

5.3.3 Approximation and aggregation of fuzzy ratings and weights of ASC sub-attributes

Using the relation between the linguistic terms and fuzzy numbers as listed in chapter 3 (Table 3.3), the linguistic terms of performance ratings and importance weights were approximated with fuzzy numbers. Since performance ratings and importance weights are given by six experts, it is essential to aggregate the fuzzy ratings and weights of agile

capabilities. There are many methods to aggregate the assessments of multiple decision-makers inputs such as arithmetic mean, median and mode but in this case study arithmetic mean was used to pool the opinions of experts. The average importance weights and performance ratings of sub-attributes were denoted respectively by R_{ijk} and W_{ijk}. The computation of R_{ijk} and W_{ijk} were carried out using following equations (Lin et al., 2006a).

$$R_{ijk} = \frac{R_{ijk1} + R_{ijk2} + \cdots + R_{ijka}}{a} \quad (5.1)$$

$$W_{ijk} = \frac{W_{ijk1} + W_{ijk2} + \cdots + W_{ijka}}{a} \quad (5.2)$$

Table 5.2: Performance rating R_{ijk} of agile capabilities titled 'Virtual Enterprise'

		E_a	E1	E2	E3	E4	E5	E6
E_i	A_{ij}	SA_{ijk}						
E_1	A_{11}	SA_{111}	G	G	G	G	G	G
		SA_{112}	VG	VG	VG	G	VG	VG
		SA_{113}	E	G	G	VG	E	G
		SA_{114}	G	G	VG	VG	VG	VG
		SA_{115}	VG	VG	E	VG	E	G
	A_{12}	SA_{121}	E	VG	VG	VG	G	E
		SA_{122}	VG	VG	E	E	G	VG
		SA_{123}	VG	VG	VG	VG	G	G
		SA_{124}	E	E	VG	VG	VG	G
		SA_{125}	VG	VG	E	G	E	G
	A_{13}	SA_{131}	G	G	G	G	E	VG
		SA_{132}	E	VG	G	VG	G	VG
		SA_{133}	G	G	E	G	E	G
		SA_{134}	G	G	G	G	G	VG
	A_{14}	SA_{141}	G	VG	G	G	VG	G
		SA_{142}	G	G	E	VG	VG	G
		SA_{143}	E	E	G	E	G	G
		SA_{144}	G	G	G	VG	G	VG
		SA_{145}	G	G	G	G	G	G
	A_{15}	SA_{151}	G	G	G	G	VG	VG
		SA_{152}	G	G	G	VG	E	G
		SA_{153}	VG	G	VG	VG	E	VG
		SA_{154}	VG	VG	VG	VG	VG	VG

Table 5.3: Importance weight of agile capabilities titled 'Virtual Enterprise'

		E_a	E1			E2			E3			E4			E5			E6		
E_i	A_{ij}	SA_{ijk}	W_i	W_{ij}	W_{ijk}	W_i	W_{ij}	W_{ijk}	W_i	W_{ij}	W_{ijk}	W_i	W_{ij}	W_{ijk}	W_i	W_{ij}	W_{ijk}	W_i	W_{ij}	W_{ijk}
E_1	A_{11}	SA_{111}	H	VH	FH	H	VH	FH	H	VH	FH	FH	H	FH	VH	H	FH	VH	H	FH
		SA_{112}			H			FH			VH			FH			H			H
		SA_{113}			VH			H			FH			VH			H			H
		SA_{114}			FH			VH			H			FH			VH			FH
		SA_{115}			VH			FH			VH			VH			H			VH
	A_{12}	SA_{121}		VH	VH		VH	H		VH	H		FH	FH		VH	FH		VH	H
		SA_{122}			H			H			VH			H			H			H
		SA_{123}			H			H			H			H			VH			VH
		SA_{124}			VH			VH			H			VH			H			H
		SA_{125}			H			H			VH			H			H			H
	A_{13}	SA_{131}		H	FH		H	FH		H	FH		H	FH		H	H		H	H
		SA_{132}			VH			VH			H			VH			VH			H
		SA_{133}			H			H			VH			H			FH			H
		SA_{134}			H			H			H			H			H			VH
	A_{14}	SA_{141}		H	H		H	FH		H	H		H	H		FH	H		H	H
		SA_{142}			H			H			VH			H			H			H
		SA_{143}			VH			VH			H			H			H			H
		SA_{144}			H			H			H			H			VH			FH
		SA_{145}			VH			VH			VH			FH			H			H
	A_{15}	SA_{151}		H	H		H	VH		H	FH		H	FH		VH	H		H	H
		SA_{152}			FH			H			H			H			FH			VH
		SA_{153}			H			FH			H			H			H			H
		SA_{154}			H			H			H			H			H			VH

Similarly average importance weights of each attributes and enablers can be given by

$$W_{ij} = \frac{W_{ij1} + W_{ij2} + \cdots + W_{ija}}{a} \tag{5.3}$$

$$W_i = \frac{W_{i1} + W_{i2} + \cdots + W_{ia}}{a} \tag{5.4}$$

Here 'a' is the number of experts involved in assigning the performance ratings and importance weights. As a sample the computation of average performance rating and average importance weight of agile supply chain sub-attribute titled 'long term relationship potential' is shown below:

- Average fuzzy performance rating of agile supply chain sub-attribute titled 'long term relationship potential' is given by the following:

$$R_{112} = \frac{[VG + VG + VG + G + VG + VG]}{6}$$

$$R_{112} = \frac{[(7,8,9) + (7,8,9) + (7,8,9) + (5,6.5,8) + (7,8,9) + (7,8,9)]}{6}$$

$$R_{112} = (6.67, 7.75, 8.83)$$

- Average fuzzy importance weight of agile supply chain sub-attribute titled 'long term relationship potential' is given by the following:

$$W_{112} = \frac{[\mathrm{H} + \mathrm{FH} + \mathrm{VH} + \mathrm{FH} + \mathrm{H} + \mathrm{H}]}{6}$$

$$\boldsymbol{W_{112}} = \frac{[(\mathbf{0.7}, \mathbf{0.8}, \mathbf{0.9}) + (\mathbf{0.5}, \mathbf{0.65}, \mathbf{0.8}) + (\mathbf{0.85}, \mathbf{0.95}, \mathbf{1.0}) + (\mathbf{0.5}, \mathbf{0.65}, \mathbf{0.8}) + (\mathbf{0.7}, \mathbf{0.8}, \mathbf{0.9}) + (\mathbf{0.7}, \mathbf{0.8}, \mathbf{0.9})]}{\mathbf{6}}$$

$$W_{112} = (0.66, 0.78, 0.88)$$

Table 5.4 shows the average performance ratings and average importance weights of agile capabilities titled 'Virtual Enterprise'. Average performance ratings and average importance weights of remaining agile capabilities are tabulated in Appendix C.

Table 5.4: Average fuzzy ratings and average fuzzy weights of agile capabilities titled 'Virtual Enterprise'

E_i	A_{ij}	SAI_{ijk}	Consolidated fuzzy ratings and weights			
			W_i	W_{ij}	W_{ijk}	R_{ijk}
E_1	A_{11}	SA_{111}	(0.72, 0.83, 0.92)	(0.78, 0.88, 0.95)	(0.50, 0.65, 0.80)	(5.00, 6.50, 8.00)
		SA_{112}			(0.66, 0.78, 0.88)	(6.67, 7.75, 8.83)
		SA_{113}			(0.72, 0.83, 0.92)	(6.50, 7.75, 8.83)
		SA_{114}			(0.65, 0.76, 0.88)	(6.33, 7.50, 8.67)
		SA_{115}			(0.77, 0.88, 0.95)	(7.17, 8.25, 9.17)
	A_{12}	SA_{121}		(0.79, 0.90, 0.97)	(0.79, 0.90, 0.97)	(7.17, 8.25, 9.17)
		SA_{122}			(0.73, 0.83, 0.92)	(7.17, 8.25, 9.17)
		SA_{123}			(0.75, 0.85, 0.93)	(6.33, 7.50, 8.67)
		SA_{124}			(0.78, 0.88, 0.95)	(7.17, 8.25, 9.17)
		SA_{125}			(0.73, 0.83, 0.92)	(6.83, 8.00, 9.00)
	A_{13}	SA_{131}		(0.70, 0.80, 0.90)	(0.57, 0.70, 0.83)	(5.92, 7.25, 8.50)
		SA_{132}			(0.80, 0.90, 0.97)	(6.58, 7.75, 8.83)
		SA_{133}			(0.69, 0.80, 0.90)	(6.17, 7.50, 8.67)
		SA_{134}			(0.73, 0.83, 0.92)	(5.33, 6.75, 8.17)
	A_{14}	SA_{141}		(0.67, 0.78, 0.88)	(0.63, 0.75, 0.87)	(5.67, 7.00, 8.33)
		SA_{142}			(0.73, 0.83, 0.92)	(6.25, 7.50, 8.67)
		SA_{143}			(0.75, 0.85, 0.93)	(6.75, 8.00, 9.00)
		SA_{144}			(0.69, 0.80, 0.90)	(5.67, 7.00, 8.33)
		SA_{145}			(0.74, 0.85, 0.93)	(5.00, 6.50, 8.00)
	A_{15}	SA_{151}		(0.73, 0.83, 0.92)	(0.66, 0.78, 0.88)	(5.67, 7.00, 8.33)
		SA_{152}			(0.66, 0.78, 0.88)	(5.92, 7.25, 8.50)
		SA_{153}			(0.67, 0.78, 0.88)	(6.92, 8.00, 9.00)
		SA_{54}			(0.73, 0.83, 0.92)	(7.00, 8.00, 9.00)

5.3.4 Calculation of FAI

FAI represents the overall agility level of the supply chain. In order to compute FAI, the agility index (AI) is calculated at the attribute level and then extended to enabler level. Agility index at the attribute level encompasses several agile sub-attributes and agility index at enabler level encompasses all agile attributes.

5.3.4.1 Calculation of AI at an attribute level

Using aggregated fuzzy ratings and fuzzy weights of ASC sub-attributes, agility index at attribute level were calculated. The following expression is made for calculation of agility index at attribute level (Vinodh and Vimal, 2012):

$$AI_{ij} = \frac{\sum_{k=1}^{n}(W_{ijk} * R_{ijk})}{\sum_{k=1}^{n} W_{ijk}} \qquad (5.5)$$

Where

R_{ijk} = Performance rating of k[th] sub-attribute in j[th] attribute in i[th] enabler.
W_{ijk} = Importance weight of k[th] sub-attribute in j[th] attribute in i[th] enabler.
AI_{ij} = Agility index of attribute in i[th] enabler.

As a sample agility index of attribute 'Partner selection' can be calculated by following:

$$\mathrm{AI}_{11} = \begin{bmatrix} (0.5, 0.65, 0.8) \otimes (5, 6.5, 8) \oplus \\ (0.66, 0.78, 0.88) \otimes (6.67, 7.75, 8.83) \oplus \\ (0.72, 0.83, 0.92) \otimes (6.5, 7.75, 8.83) \oplus \\ (0.65, 0.76, 0.88) \otimes (6.33, 7.5, 8.67) \oplus \\ (0.77, 0.88, 0.95) \otimes (7.17, 8.25, 8.67) \end{bmatrix} / \begin{bmatrix} (0.5, 0.65, 0.8) \oplus \\ (0.66, 0.78, 0.88) \oplus \\ (0.72, 0.83, 0.92) \oplus \\ (0.65, 0.76, 0.88) \oplus \\ (0.77, 0.88, 0.95) \end{bmatrix}$$

Where $\otimes$ is multiplication operator and $\oplus$ addition operator. These two operators are also used in remaining part of chapter.

AI_{11} = (6.43, 7.61, 8.72)

Using the same principle, the index pertaining to the various agility attributes is calculated and is shown in Table 5.5.

Table 5.5: Agility index for each ASC attributes

E_i	A_{ij}	W_i	W_{ij}	AI_{ij}
E_1	A_{11}	(0.72, 0.83, 0.92)	(0.78, 0.88, 0.95)	(6.43, 7.61, 8.72)
	A_{12}		(0.79, 0.90, 0.97)	(6.94, 8.05, 9.04)
	A_{13}		(0.70, 0.80, 0.90)	(6.02, 7.32, 8.55)
	A_{14}		(0.67, 0.78, 0.88)	(5.88, 7.21, 8.47)
	A_{15}		(0.73, 0.83, 0.92)	(6.40, 7.57, 8.71)
E_2	A_{21}	(0.67, 0.78, 0.88)	(0.53, 0.68, 0.82)	(5.50, 6.88, 8.25)
	A_{22}		(0.53, 0.68, 0.82)	(5.49, 6.88, 8.25)
	A_{23}		(0.53, 0.68, 0.82)	(5.57, 6.94, 8.29)
	A_{24}		(0.59, 0.73, 0.85)	(6.11, 7.33, 8.56)
E_3	A_{31}	(0.77, 0.88, 0.95)	(0.79, 0.90, 0.97)	(6.34, 7.56, 8.70)
	A_{32}		(0.77, 0.88, 0.95)	(5.54, 6.90, 8.26)
	A_{33}		(0.74, 0.85, 0.93)	(6.59, 7.79, 8.85)
E_4	A_{41}	(0.70, 0.80, 0.90)	(0.57, 0.70, 0.83)	(5.83, 7.17, 8.44)
	A_{42}		(0.73, 0.83, 0.92)	(5.81, 7.15, 8.43)
	A_{43}		(0.79, 0.90, 0.97)	(5.38, 6.80, 8.20)
	A_{44}		(0.73, 0.83, 0.92)	(5.40, 6.82, 8.21)
E_5	A_{51}	(0.70, 0.80, 0.90)	(0.70, 0.80, 0.90)	(6.76, 7.83, 8.89)
	A_{52}		(0.73, 0.83, 0.92)	(6.40, 7.58, 8.71)
	A_{53}		(0.73, 0.83, 0.92)	(6.42, 7.56, 8.71)
E_6	A_{61}	(0.73, 0.83, 0.92)	(0.75, 0.85, 0.93)	(5.68, 7.06, 8.38)
	A_{62}		(0.67, 0.78, 0.88)	(5.68, 7.01, 8.34)
	A_{63}		(0.67, 0.78, 0.88)	(5.08, 6.56, 8.04)
E_7	A_{71}	(0.53, 0.68, 0.82)	(0.57, 0.70, 0.83)	(5.39, 6.81, 8.21)
	A_{72}		(0.57, 0.70, 0.83)	(5.78, 7.08, 8.25)
	A_{73}		(0.57, 0.70, 0.83)	(5.72, 7.06, 8.37)

5.3.4.2 Calculation of AI at the enabler level

Using the agility index of ASC attributes, calculation of agility index at enabler level can be done. The following expression is used for calculation of agility index at enabler level (Vinodh and Vimal, 2012):

$$AI_i = \frac{\sum_{j=1}^{m}(W_{ij} * AI_{ij})}{\sum_{j=1}^{m} W_{ij}} \tag{5.6}$$

Where

AI_{ij} = Agility index of j^{th} attribute in i^{th} enabler.
W_{ij} = Importance weight of j^{th} attribute in i^{th} enabler.

AI_i = Agility index of i[th] enabler.

As a sample agility index of enabler 'Virtual Enterprises' can be calculated using following expression

$$\mathrm{AI}_1 = \begin{bmatrix} (0.78, 0.88, 0.95) \otimes (6.43, 7.61, 8.72) \oplus \\ (0.79, 0.9, 0.97) \otimes (6.94, 8.05, 9.04) \oplus \\ (0.7, 0.8, 0.9) \otimes (6.02, 7.32, 8.55) \oplus \\ (0.67, 0.78, 0.88) \otimes (5.88, 7.21, 8.47) \oplus \\ (0.73, 0.83, 0.92) \otimes (6.4, 7.57, 8.71) \end{bmatrix} / \begin{bmatrix} (0.78, 0.88, 0.95) \oplus \\ (0.79, 0.9, 0.97) \oplus \\ (0.7, 0.8, 0.9) \oplus \\ (0.67, 0.78, 0.88) \oplus \\ (0.73, 0.83, 0.92) \end{bmatrix}$$

AI_1 = (6.36, 7.57, 8.70)

Using the same principle, agility index for remaining enablers are calculated as shown in Table 5.6.

Table 5.6: Agility index for each ASC enablers

Enabler	W_i	AI_i
1	(0.72, 0.83, 0.92)	(6.36, 7.57, 8.70)
2	(0.67, 0.78, 0.88)	(5.68, 7.01, 8.34)
3	(0.77, 0.88, 0.95)	(6.15, 7.41, 8.60)
4	(0.70, 0.80, 0.90)	(5.59, 6.97, 8.32)
5	(0.70, 0.80, 0.90)	(6.52, 7.65, 8.77)
6	(0.73, 0.83, 0.92)	(5.49, 6.88, 8.26)
7	(0.53, 0.68, 0.82)	(5.63, 6.98, 8.28)

5.3.4.3 Determination of FAI

Fuzzy agility index (FAI) of a supply chain can be calculated using the following equation (Vinodh and Vimal, 2012):

$$\mathrm{FAI} = \frac{\sum_{i=1}^{l} (W_i * AI_i)}{\sum_{i=1}^{l} W_i} \qquad (5.7)$$

Where
AI_i = Agility index of i[th] enabler.
W_i = Importance weight of i[th] enabler.
FAI = Overall Agility Index of supply chain

$$\text{FAI} = \begin{bmatrix} (0.72, 0.83, 0.92) \otimes (6.36, 7.57, 8.70) \oplus \\ (0.67, 0.78, 0.88) \otimes (5.68, 7.01, 8.34) \oplus \\ (0.77, 0.88, 0.95) \otimes (6.15, 7.41, 8.60) \oplus \\ (0.7, 0.8, 0.9) \otimes (5.59, 6.97, 8.32) \oplus \\ (0.7, 0.8, 0.9) \otimes (6.52, 7.65, 8.77) \oplus \\ (0.73, 0.83, 0.92) \otimes (5.49, 6.88, 8.26) \oplus \\ (0.53, 0.68, 0.82) \otimes (5.63, 6.98, 8.28) \end{bmatrix} / \begin{bmatrix} (0.72, 0.83, 0.92) \oplus \\ (0.67, 0.78, 0.88) \oplus \\ (0.77, 0.88, 0.95) \oplus \\ (0.7, 0.8, 0.9) \oplus \\ (0.7, 0.8, 0.9) \oplus \\ (0.73, 0.83, 0.92) \oplus \\ (0.53, 0.68, 0.82) \end{bmatrix}$$

FAI = (5.92, 7.22, 8.47)

5.3.5 Determination of Euclidean distance to match FAI with an approximate agility level

After finding the fuzzy agility index (FAI), it can be matched with linguistic terms. For this purpose Euclidean distance method was adopted because it is the most intuitive method in perceiving proximity (Vinodh *et. al*., 2013). In this study the following linguistic terms are used for labelling in order to determine the ASC level. The linguistic terms and fuzzy numbers used are shown in Table 5.7 (Lin et al., 2006b).

Table 5.7: Natural-language expression set for labelling the agility level

Symbol	Linguistic terms	Fuzzy number
EA	Extremely Agile	(7, 8.5, 10)
VA	Very Agile	(5.5,7,8.5)
A	Agile	(3.5,5,6.5)
FA	Fairly Agile	(1.5,3,4.5)
SA	Slowly Becoming Agile	(0,1.5,3)

Now using the Euclidean distance method the Euclidean distance D between FAI and AL (Agility level) was calculated using following formula (Vinodh and Devadasan, 2011).

$$D(\text{FAI}, \text{AL}) = \left\{ \sum_{x \in p} [f_{\text{FAI}}(x) - f_{AL}(x)]^2 \right\}^{1/2} \quad (5.8)$$

$$D(FAI, EA) = \{(5.92 - 7)^2 + (7.22 - 8.5)^2 + (8.47 - 10)^2\}^{1/2}$$

$$D(FAI, EA) = 2.2684$$

Similarly other Euclidean distances are tabulated in Table 5.8.

Table 5.8: Euclidean distance to match FAI with all agility level

Euclidean distance	Corresponding numerical value
D(FAI, EA)	2.2684
D(FAI, VA)	**0.4751**
D(FAI, A)	3.8296
D(FAI, FA)	7.2874
D(FAI, SA)	9.8836

Thus, by matching a linguistic label with the minimum D, the agility index level of the supply chain of case organization is assessed as 'Very Agile', as shown in Figure 5.3.

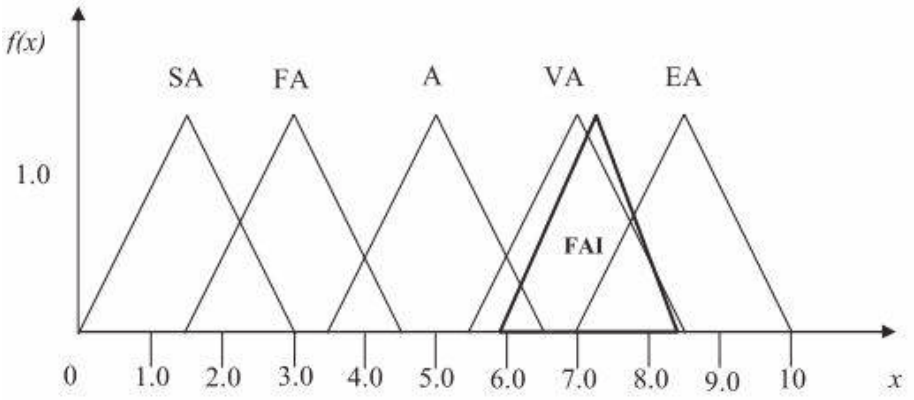

Figure 5.3: Linguistic levels to matching FAI

Matching of the FAI (Agility level of case-organization) with linguistic terms of the natural language expression set (Standard agility level) can also be shown by bar diagram which is depicted in Figure 5.4.

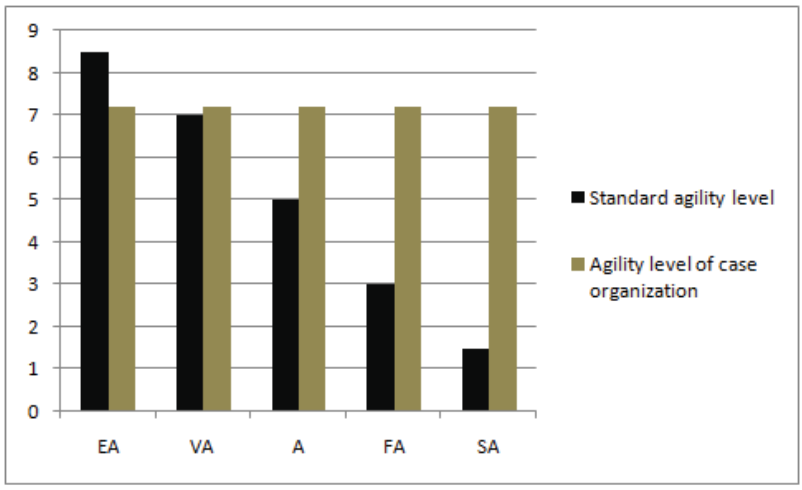

Figure 5.4: Matching of the standard agility level with agility level of the case supply chain using bar diagram

5.4 Analysis and identification of barriers for improving the agility level

Although agility level of considered case supply chain is 'Very Agile' but it is far away from 'Extremely Agile'. It is due to barriers within the supply chain which could have impacted the agility level. These barriers can be obtained by calculating fuzzy performance importance index (FPII). The following equations can be used to obtain the FPII (Lin et al., 2006a; 2006b; Vinodh et al., 2013):

$$FPII_{ijk} = W'_{ijk} \otimes R_{ijk} \quad (5.9)$$

$$W'_{ijk} = \left[(1,1,1,) - W_{ijk}\right] \quad (5.10)$$

Where

R_{ijk} = Performance rating for ASC sub-attribute *ijk*
W_{ijk} = Importance weight for ASC sub-attribute *ijk*

A sample calculation of FPII of ASC sub-attribute 'Compatibility of supplier with your company' is as shown below.

$$FPII_{111} = [(1,1,1,) - W_{111}] \otimes R_{111}$$

$$FPII_{111} = [(1,1,1,) - (0.50, 0.65, 0.80)] \otimes (5.00, 6.50, 8.00)$$

$$FPII_{111} = (0.50, 0.35, 0.20) \otimes (5.00, 6.50, 8.00)$$

$$FPII_{111} = (2.50, 2.28, 1.60)$$

Similarly, the FPII of all 101 ASC sub-attributes are computed and tabulated in Appendix D. Since fuzzy numbers do not always yield a totally ordered set as real numbers do, all the FPIIs must be ranked (Lin et al. 2006b). There are many methods available in the literature to rank the fuzzy numbers. In present Chapter centroid method is used to rank the FPIIs. The reason behind this is that centroid method is simple and easy to implement (Vinodh et al., 2013). Using centroid method ranking score can be calculated by following equation (Vinodh and Vimal, 2012):

$$\text{Ranking score} = \frac{(a + 4b + c)}{6} \qquad (5.11)$$

Where

$a =$ Lower number of triangular fuzzy number

$b =$ Middle number of triangular fuzzy number

$c =$ Upper number of triangular fuzzy number

The ranking score of sub-attribute 'Compatibility of supplier with your company' are 2.20. The same procedure is followed to calculate the ranking of other ASC sub-attributes. Ranking score of all other ASC sub-attributes are also tabulated in Appendix D. To identify the barriers of agility, experts were asked to set the threshold value to decide the agility barriers. Sub-attributes that have ranking score less than threshold value are obstacles to the agility in the supply chain. These sub-attributes are called barriers of

agility. The threshold value for present problem is set to 0.90 by experts. Table 5.9 shows eleven ASC sub-attributes, whose performance is lower than threshold value. These eleven ASC sub-attributes are called as the barriers of agility. Identified barriers help to improve the weaker areas of supply chain in order to improve agility level. In Figure 5.5 scatter plot is drawn to see where the ranking score lies.

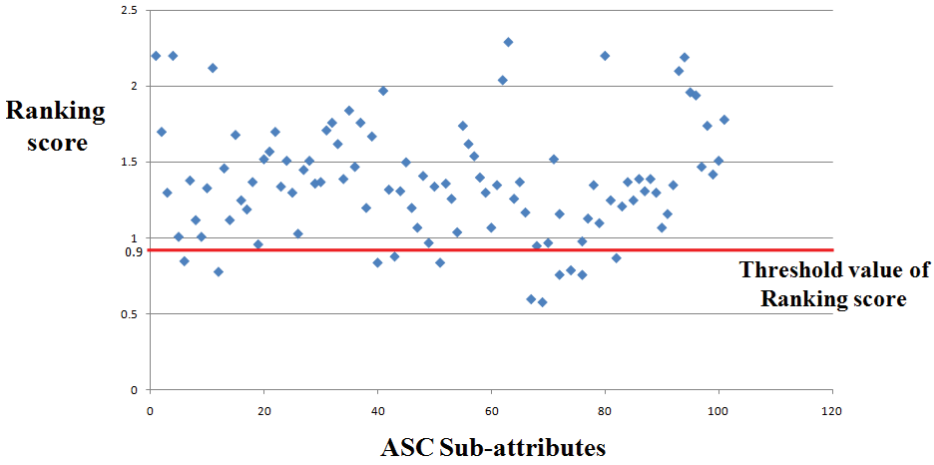

Figure 5.5: Scatter plot of the FPII of all sub-attributes

Table 5.9: Barriers identified in the supply chain

Barriers of agility in the supply chain	Ranking score
Control over outsourced component	0.85
Availability of efficient equipment and resources for transportation	0.78
Impact on organization performance	0.84
Responsiveness of the business process	0.88
Market size	0.84
Product certification	0.60
Provide product manual	0.58
Continuous monitoring	0.76
Guarantee and warranty of product	0.79
Stay in touch with customer	0.76
Adaptability of not functioning of machinery and equipment	0.87

5.5 Sensitivity of the barriers list to the threshold value

The present results shows that the case-organization is 'very agile' which is the below than 'extremely agile'. If results would have obtained 'extremely agile' which means there is no any obstacle to agility. The result 'very agile' indicated that there are some obstacles to agility. And after setting threshold value of ranking score 0.9, 11 barriers were obtained. If we decrease the threshold value of ranking score, then number of barriers will decrease and hence case-organization tends to be 'extremely agile'. And if we increase the threshold value of ranking score, then number of barriers will increase which means agility level will tends to lower levels.

5.6 Signification of findings organization to be "Very Agile"

In this chapter, a conceptual model developed, to determine the overall agility level of the case-organization. From the analysis, it is observed that the organization on which the study was performed is "Very Agile". The term very agile indicates that case-organization is not only insuring the proper raw material supplies to produce the final product, but also it is nimble enough to meet fluctuating customer demands in a profitable way. Though case-organization is very agile but the agility level identified here is not at an excellence level which could be "Extremely Agile". This means that there must be some loophole which can be caused for big problem in future for case-organization. This loophole can be called as obstacles to the case-organization which is responsible for being short from standard agility level. It should be noted that in big organization, generally managers are not concerned about small problems, and these small problems sometimes may be the cause of bigger problems. Hence this chapter also provides improvement directions for the organisation to become extremely agile for surviving in the competitive situation by identifying the barriers of agility. To identify these barriers, the FPII is calculated. Overall, 11 barriers were identified in the study. These barriers are week area for case-organization.

With the help of identified barriers, managers can improve the weaker areas of the supply chain. After working on these weeks area case-organization can become extremely agile.

5.7 Cost benefit trade-offs with agility

To increase agility level, supply chain manager has to quickly adjust its supply chain tactics and operations. However, because change is costly and achieving agility often involves sacrificing efficiency. Hence it is necessary for supply chain manager to maximise agility of supply chain deploying input resources that is operating cost, management hour and employee hour. In the view of this, an AHP-GP model is developed in Chapter 7, which controls the agility of supply chain by controlling the agility enablers and by deploying input resources (operating cost, management hour and employee hour).

5.8 Significance of the finding of the barriers

The result of agility assessment model indicates that the agility level of case-organization is "Very Agile". Although the agility level of the considered case supply chain is "very agile", it is far from "extremely agile". This is due to barriers within the supply chain that could have impacted the agility level. These barriers are obtained by calculating fuzzy performance importance index (FPII) of ASC sub-attributes. The FPII are in fuzzy form and it is converted to real number by using centroid method. Sub-attributes that have FPII value less than threshold value are obstacles to the agility in the supply chain. These sub-attributes are called barriers of agility. The threshold value for present problem is set to 0.90 as suggested by experts. There are eleven ASC sub-attributes, whose performance is lower than threshold value and hence these are the roadblocks in achieving the "extremely agile" status for the organization.

The first barrier is '*control over outsourced component*' whose Performance Importance Index (PII) is 0.85. It was found that there is less control over outsourced component by

case-organization. For case-organization controlled outsourcing is to be needed. Outsourcing is normally considered when your company doesn't have the capability to perform the specific task, or when your company believes that another organisation can perform the task better. According to CAG report (24 July, 2017) the case-organization outsource and procure few parts and components from foreign companies on higher cost than Indian company. For example, in 2013-14 case-organization procured 127crankcase from EMD (USA) at a rate of 149 lakh per unit even though Indian manufacturer situated at Panchkula was offering at price of 70 lakh per unit. This results in the financial loss for case-organization. Organization can get over to this barrier by outsourcing from the Indian manufacturers.

The second barrier identified here is '*availability of efficient equipment and resources for transportation*' with PPI value 0.78. The products of case-organization are very heavy and large in size. Transportation of these products from one workshop to other workshop is time consuming. There is a requirement of efficient equipment and resources for quick transportation. Case-organization can go for latest and automated equipments for transportation.

Next barrier is '*impact on organization performance*' which has PII is 0.84. Case-organization is investing in Information Technology tools and software but its impact on organization performance might not as good as require. This has been also verified by the senior executive of the organization. This can be overcome by giving regular training to employees about tools and software.

The fourth barriers identified here is '*responsiveness of the business process*'. The PII of this barrier is 0.88 which is almost closer to threshold value; due to this it will not give severe influence on negative side. Case-organization's all departments share information to

make the fluent information flow so as to improve the responsiveness of the change and the process from downstream/upstream. It was found during the visit of the case-organization that, there may be slightly improper flow of information among all the departments which affects the responsiveness of the business processes.

In the continuation of this the fifth barrier is '*market size*' with PII 0.84. It was found that the case-organization exports to the countries such as Tanzania, Sri Lanka, Bangladesh, Vietnam, Malaysia, Myanmar, Angola, Senegal, Mali, Sudan and Mozambique. The case-organization produces more than 342 locos per annum. As the case-organization has big market size, it is difficult to analysis market trend correctly.

'*Product certification*' is next barriers to agility with PII (0.60). Product of case-organization is certified under ISO 9001 certification scheme till the date of this research. ISO 9001 is Economic aspect of certification. But according to quality expert only this certification is not sufficient. Organization has to get following certifications also (1) Environmental aspect - ISO 14001, (2) Social aspect - ISO 26000. It was found that case-organization is certified ISO 14001 recently.

Now coming out to the seventh barrier which is nothing but '*provide product manual*' having PII is (0.58). Product manual is a technical communication document intended to give assistance to people using a particular system of product. Case-organization provides effective product manual. The problem is that the language of product manual is English and the customers of the case-organization have their own languages.

'*Continuous monitoring*' having PII (0.76) is eighth agility barrier identified here. It is observed from the visit of the case-organization that there is lack of continuous monitoring during the quality control process. Employees have to give full attention for the continuous monitoring process.

The ninth and tenth barrier are '*guarantee and warranty of product*' and '*stay in touch with customer*' with Performance Importance Index (PII) are (0.79) and (0.76). These two barriers are the sub-attributes of the Customer Service. For the customer satisfaction these two sub-attributes play an important role. Here case-organization is not able to provide proper customer service due to language barriers. Different languages are spoken and written in different countries. To stay in touch with customer and to provide all the assistance related to product guarantee and warranty it is required for case-organization to know the language of their customers or employ somebody who knows that language.

Final and eleventh agility barrier is '*adaptability of not functioning of machinery and equipment*' (PII = 0.87). From the observation of the plant it is found that when work equipment deteriorate, management team takes too much time to respond. Equipment failure is a common problem for many organizations. In order to avoid this, large machineries should be inspected at regular intervals.

5.9 Generality of the findings obtained from this chapter

The findings from Chapter 5 are seven ASC enablers, 126 agile capabilities (25 ASC attributes and 101 ASC sub-attributes) and 11 barriers. This approach is useful to other organizations also but ASC capabilities may slightly differ. All other manufacturing organizations face same business situations such as uncertainty, global competition and complexity in a business environment. Production systems of all other manufacturing may be small, medium or large but they all are involved in the practice of partner selection, outsourcing for procuring raw-materials or semi-finished product in order to manufacturing the final products. For this purpose they are making temporary alliance with other enterprises, they are making collaborative relationship with them in order to satisfy their costumer. All the manufacturing organizations have almost similar type of production planning and control process; they all use latest information technologies tools. They

all are concerned with the real demand of product and changes therein. For this purpose they all analysing the market trends, forecasting the demand and surveying the markets.

Customer satisfaction is important aspect of all the manufacturing organizations. They all involve in controlling the quality of product, providing the quality assurance and customer service to their customer. Hence for customer satisfaction, all the manufacturing organizations are making their supply chain flexible as well as they are also predicting unexpected changes in the business environment and, therefore, appropriately adapting to these changes.

5.10 Concluding remarks

Agile manufacturing is the competitive manufacturing strategy which enables the organisation to survive and prosper in the competitive market scenario. The evaluation of agility gains extreme importance as it is an indicator of the organisational excellence. The agility level would ensure that the practicing managers know about how much their supply chain agility is short of being 'extremely agile'. If there is a gap between their agility level and standard agility level, then it is recommended to identify the barriers within the supply chain for agility improvement.

This Chapter reports a research study in which seven ASC enablers are selected for measuring the agility of a supply chain. These seven enablers are solely responsible for agility in the supply chain. In this chapter, along with seven enablers, 25 attributes and 101 sub-attributes are identified. These enablers, attributes and sub-attributes are called agile capabilities. The study begins with the identification of agile capabilities which is carried out through the literature review and finalized with the help of experts. To assess the agility, the concept of a multi-grade fuzzy logic approach is used. There are wide varieties of agility measurement methodologies that have been reported in literature. The reason for

selecting fuzzy logic approach as solution methodology is that, compared to other techniques fuzzy logic approach has capability to handle vague and uncertainty situations. FAI represents the overall agility level of a supply chain. In order to compute FAI, the AI is calculated at the attribute level and then extended to an enabler level. The AI at the attribute level encompasses several agile sub-attributes and the AI at the enabler level encompasses all agile attributes. After using a fuzzy logic approach, it was found that the case supply chain is 'very agile', although it is below the 'extremely agile'. It is found that there are a few barriers within the supply chain that impact the agility level. To identify these barriers, the FPII is calculated. Sub-attributes that have FPII value less than threshold value are obstacles to the agility in the supply chain. These sub-attributes are called barriers of agility. The threshold value for present problem is set to 0.90 as suggested by experts. There are eleven ASC sub-attributes, whose performance is lower than threshold value and hence these are the roadblocks in achieving the "extremely agile" status for the organization.

The agility evaluation model presented in this Chapter is an important gauge for the performance measurement of the supply chain. The contemporary supply chain managers can measure the agility level of their supply chain periodically using this model. After the agility evaluation, barriers to supply chain can be identified. These barriers are the roadblocks in achieving the "extremely agile" status for the organization. After identifying the barriers the comprehensive improvement plan can be proposed for each enabler. With the help of comprehensive improvement plan, managers can improve the weaker areas of the supply chain. The agility assessment method explained in this chapter could be used as a test kit for periodically evaluating the agility level of the any organisation. The difference is that, there might be slightly change in agile capabilities for different organization.