Chapter 4

Supply Chain Flexibility Performance Measurement using Fuzzy Analytic Hierarchy Process

The previous Chapter presents integration of AHP with BSC and the Performance Prism to evaluate contribution of performance indicators in achieving organizational goal, prioritise its resource deployment and comparing performance of supply chains. This chapter proposes a method to determine flexibility performance measure of a supply chain using modified Fuzzy Analytic Hierarchical Process. A comparative analysis of some widely-cited performance measurement systems for supply chain flexibility have also been undertaken in this chapter. The usage of suggested measurement framework is also demonstrated using sample data.

4.0 INTRODUCTION

'Flexibility' is one of the pillars of effective SCM practices (Fantazy, Kumar, & Kumar, 2009) and therefore is a strategic and key area of importance. In recent times, 'flexibility' is considered as a critical area in which SC compete (Gunasekaran et al., 2004). Different perspectives of supply chain performance measure are available in literature as brought out in Chapter 2. Flexibility and agility in supply chain have been considered as one of the performance parameters in many studies; however, detailed study focusing on measurement of flexibility in supply chain is limited (Duclos, Vokurka, & Lummus, 2003; X. Li, Goldsby, & Holsapple, 2009). Though flexibility in manufacturing has been addressed in detail (Sethi & Sethi, 1990), measurement of flexibility in large, complex systems, such as SCs has rarely been addressed (X. Li et al., 2009)." Taxonomy of flexibility performance measurement is proposed by many authors (Fantazy et al., 2009; Hoek, Harrison, & Christopher, 2001; Vickery, Calantone, & Droge, 1999), however its implementation models are not available. "Beamon (1999) has proposed a framework for measurement of flexibility in SC and identified performance measures for flexibility in SC. Duclos, Vokurka, & Lummus (2003) had suggested a SC flexibility framework based on six SC components while Pujawan (2004) had suggested an improved version of Duclos et al. (2003) conceptual flexibility measurement framework.

This chapter examines performance measurement aspects of flexibility in SC context and suggests a framework to determine flexibility performance measure of a SC using modified Fuzzy Analytic Hierarchical Process (FAHP). A comparative analysis of some widely-cited PMS for SC flexibility has also been discussed in this chapter. The usage of suggested measurement framework is also demonstrated using sample data.

4.1 Flexibility in Supply Chain

Beginning of the industrial revolution saw companies striving for 'cost reduction' through 'mass production'. The strategic objectives have later changed from 'cost reduction through mass production' to 'quality' mainly due to the efforts of W E Deming and Joseph M Juran. Both the 'cost reduction' and 'quality revolution' paradigms focussed on the internal functioning of the organisation. However, after 1990s, 'Responsiveness, Innovation and Flexibility' emerged as the strategic imperatives for a business organisation's success and progress (Duclos et al., 2003). Organisations realised that 'Responsiveness', 'Innovation' and 'Flexibility' is achievable only through a SC perspective and this led to the new paradigm of SCM. The initial objectives of mass production and cost efficiency have now changed to 'Flexibility', 'Innovation' and 'Responsiveness' of the SC and managing across enterprises (Duclos et al., 2003; Lummus & Vokurka, 1999). Lee (2004) observes that many organisations continue to focus on the speed and costs of their SCs without realising the importance of flexibility.

Effectively managing SC operations is critical to any organisation's ability to compete in today's global and dynamic environment. Good SC management practices results in a variety of advantages such as increased customer value, increased profitability, reduced cycle times, less inventory levels (Christensen et al., 2007) and increased flexibility (Hoek et al., 2001). Organisations are becoming increasingly aware that for competing in continuously changing environment, it is necessary to monitor, understand and control their flexibility capabilities (Stevenson & Spring, 2007). Only a flexible SC with inbuilt flexibility capabilities will be able to cope with the fast changes in the competitive and dynamic environment (Pujawan, 2004; Vickery et al., 1999). Flexibility and agility are related; the important attribute of an agile SC is flexibility (Christopher, 2000).

Supply chain flexibility is defined in different ways by different authors. Kumar, Fantazy, Kumar, & Boyle, (2006) defines supply chain flexibility as "the ability of supply chain partners to restructure their operations, align their strategies, and share the responsibility to respond rapidly to customer's demand at each link of the chain, to produce a variety of products in the quantities, costs, and qualities that customers expect, while still maintaining high performance". Vickery et al. (1999) defined five supply chain flexibilities namely product, volume, launch, access, and responsiveness flexibility. According to Beamon (1999), flexibility measures how well the system reacts to uncertainty and its ability to respond to a changing environment. Based on literature review, Stevenson & Spring (2007) concluded the following:

1. "Flexibility is multi-dimensional"
2. "Importance of the elements of flexibility varies in different supply chains"
3. "Flexibility is a capability that does not have to be demonstrated"

"Many authors thus indicate flexibility as a complex and multidimensional concept ((Sánchez & Pérez, 2005). Lee (2004) states that 'agility' and 'adaptability' are two vital elements contributing to supply chain success. Lee (2004) defines 'agility' in SC as capability to respond to short-term changes in demand or supply quickly and handle external disruptions smoothly and defines 'adaptability' as the capability to adjust SC's design to meet structural shifts in markets; modify supply network to strategies, products, and technologies. However, a simple definition of flexibility may be given as the ability to change or react with no handicap in performance, time, effort or cost. It can be inferred that, being a flexible SC means having the capability to provide products and services that meet the individual demands of customers (Gunasekaran et al., 2004) and partners of the SC."

"Literature indicates several advantages of flexible SCs (Beamon, 1999b; Hoek et al., 2001; X. Li et al., 2009; Primrose, 1996; Sánchez & Pérez, 2005). Significant of them are enumerated as under:

1. Reduction in the number of backorders
2. Reduction in lost sales
3. Increased customer satisfaction
4. Ability to respond to demand variations, such as trends
5. Ability to accommodate periods of poor manufacturing performance
6. Ability to accommodate periods of inadequate supplier performance
7. Ability to accommodate periods of inadequate delivery performance

8. Ability to respond to natural calamities, political changes and unforeseen events
9. Ability to respond to new competitors and new products

When a SC aligns itself for higher levels of flexibility, the SC will lose the opportunity to exploit the economies of scale in many of its activities. There is an argument that for functional products such as salt, milk, mineral water etc., the need of flexibility is much less. The customer demand is relatively constant and there is less scope of product variety in these functional products. On the other hand, innovative products such as mobile phones and fashion products have lesser product life cycle and therefore needs higher levels of supply chain flexibility. This implies that the stress of the SC in responding to different types of products should be different as far as the desired flexibility level is concerned. Supply chains supplying innovative products should pursue flexibility while for functional products costs should be the primary focus. There will be a need to arrive at the right flexibility level for a given SC.

Many authors agree to the view that different supply chains need varying degrees of flexibility (Duclos et al., 2003; Fantazy, Kumar, & Kumar, 2008). However, the method to arrive at the ideal amount of flexibility for a given SC is not clearly elaborated in the literature reviewed. According to Kumar et al. (2006) in order to conceive and formulate its flexibility requirement, an organization need to assess the environment in which the organisation functions including its relationship with stakeholders and evaluate the risks and uncertainties. This assessment will help in the development of other functional flexibilities namely, 'Sourcing Flexibility', 'Product Flexibility' and 'Delivery Flexibility'. Pujawan (2004) has suggested a list of drivers of flexibility in SCs. These 'drivers' of flexibility can form as a basis of determining how much flexibility is needed for a selected SC.

After deciding on the requirement of flexibility at different levels in the SC, the next challenge is its implementation. In a SC environment, it is imperative that the supply chain partners must share the responsibility of implementing and managing the required SC flexibility (Kumar et al., 2006). Vickery et al. (1999), in their research on SC flexibility, proposed that manufacturing is generally responsible for volume flexibility, marketing is generally responsible for distribution flexibility, and research and design is responsible for new product introduction flexibility. Kumar et al. (2006) also suggests that the responsibility for achieving each type of required SC flexibility must be shared by various stakeholders.

4.2 Measurement of Flexibility in SC

Flexibility measures potential behavior and therefore flexibility does not have to be demonstrated by system to exist. There have been attempts to create a framework for agile SC and its measurement (Hoek et al., 2001) and development of an instrument to measure SC agility (X. Li et al., 2009). Beamon, (1999) proposed a framework for measurement of flexibility in SC and identified performance measures for flexibility in SC. Kumar et al. (2006) have developed a conceptual framework for implementing and managing SC flexibility and also suggested taxonomy for performance measurement. Fantazy et al. (2009) examined relationships among strategy, flexibility, and performance in SC context. In this work, they have identified 38 parameters which will contribute to SC flexibility. Duclos et al. (2003) have suggested six components for SC flexibility based on literature. (Pujawan, 2004) proposed a framework for assessing flexibility of a SC with four main constituents of flexibility. The four dimensions of flexibility identified are: flexibility of product delivery system, production system, product development and supply system. In each of these four dimensions, number of pertinent elements are identified which contributes to flexibility. A general guideline for conducting flexibility assessment is also presented in this work. The framework allows a SC manager to compare between desired and current capability of a SC in various flexibility dimensions (Pujawan, 2004).

4.3 Modified Fuzzy AHP for Performance Measurement

AHP is a general problem solving method developed for making complex decisions based on variables that do not have exact numerical consequences (Saaty, 2008) as mentioned in Chapter 3. Detailed procedure of APH methodology is also available in literature (Forman & Gass, 2001; Saaty, 2008; Ug, 2008). Limitation of AHP approach is that it is incapable of handling inherent subjectivity and ambiguity related to the mapping of perception to an exact value. This led to development of fuzzy AHP. Fuzzy AHP methodology is designed for decision making problems and selecting best of alternatives by join in idea of fuzzy set theory and AHP. With Fuzzy AHP, decision makers feel more confident and can employ both his quantitative information and qualitative knowledge (Cho et al., 2012). Different versions of Fuzzy AHP methods have been proposed in literature (Adel El-Baz, 2011; Cho et al., 2012). This work is based on Extent Analysis Method of Fuzzy AHP proposed by (Veerabathiran & Srinath, 2012).

A fuzzy number is defined on universe R as a convex and normalised fuzzy set. A triangular fuzzy number expresses relative strength of each pair of elements in the same hierarchy and can be denoted as M = (l, m, u), where l ≤ m ≤ u. The parameters l; m; u; indicate the smallest possible value, most promising value, and largest possible value respectively. The triangular type membership function is shown in Figure 4.1. A triangular fuzzy number A with membership function $\mu_A(x)$ is defined on R by:

$$\mu_A(x) = \begin{cases} 0; & x < l \text{ or } x > m \\ (x-1) / (m-l); & l \leq x \leq m \\ (x-u) / (m-u) & m \leq x \leq u \end{cases} \qquad \text{(Eq. 4.1)}$$

Extent analysis method is used to consider the extent to which an object can satisfy the goal, i.e., satisfaction extent. In this method, the ‘extent’ is quantified by using a fuzzy number. Based on fuzzy values for extent analysis of each object, a fuzzy synthetic degree value can be obtained, which is defined as follows:

$X = \{x_1, x_2, ...x_n\}$ be object set and $G = \{g_1, g_2 ..... g_m\}$ be goal set. According to extent analysis method, each object is taken and extent analysis for each goal, g_i, is performed. Thus, m extent analysis values for each object can be obtained which are denoted as M^j_{gi} (i=1,2, ...n and j=1,2, ...m). M^j_{gi} are triangular fuzzy numbers.

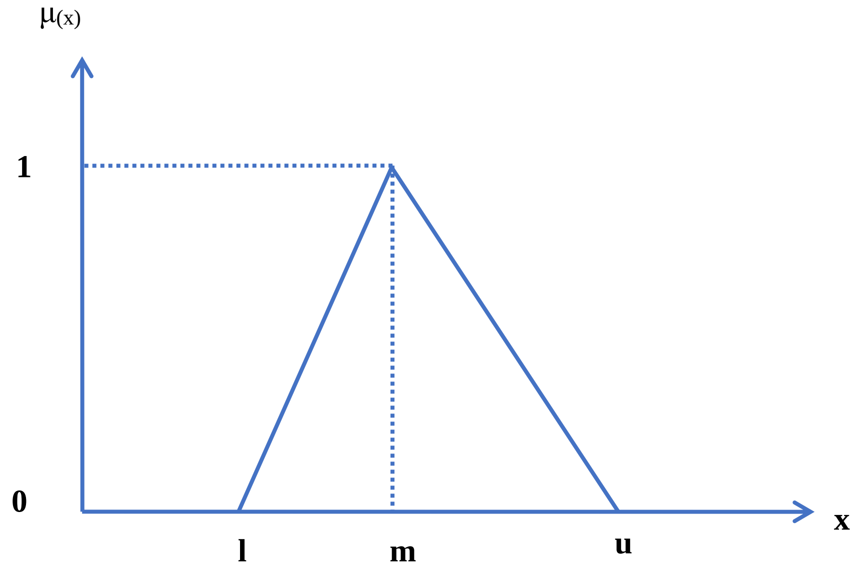


Figure 4.1 Triangular Fuzzy Number

Value of fuzzy synthetic extent with respect to the ith object is:

$$S_i = \sum_{j=1}^{m} M_{g_i}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} \right]^{-1} \qquad \text{(Eq. 4.2)}$$

Where,

$$\sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{j=1}^{m} l_{ij}, \sum_{j=1}^{m} m_{ij}, \sum_{j=1}^{m} u_{ij} \right), i = 1, 2, \ldots\ldots, n, \qquad \text{(Eq. 4.3)}$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{i=1}^{n} \sum_{j=1}^{m} l_{ij}, \sum_{i=1}^{n} \sum_{j=1}^{m} m_{ij}, \sum_{i=1}^{n} l_{ij} \sum_{j=1}^{m} u_{ij} \right) \qquad \text{(Eq. 4.4)}$$

Inverse of this equation (Eq. 4.4) is calculated as:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = \left[\frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{m} l_{ij}}, \frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{m} m_{ij}}, \frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{m} u_{ij}} \right] \qquad \text{(Eq. 4.5)}$$

The next step is to find degree of possibility between M_1 and M_2. Refer Figure 4.2 to see intersection between M_1 and M_2. Degree of possibility of $M_1 \leq M_2$ is:

$$V(M_2 \geq M_1) = \sup_{y \geq x} \left[\min\left(\mu_{M_1}(x), \mu_{M2}(y) \right) \right] =$$

$$hgt(M_2 \cap M_1) = \mu_{M_2}(d) = \left\{ \begin{array}{l} 1, if\ m_2 \geq m_1 \\ 0, if\ l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, otherwise \end{array} \right\}$$ (Eq. 4.6)

Where d is the ordinate of the highest intersection point D (refer Figure 4.2)

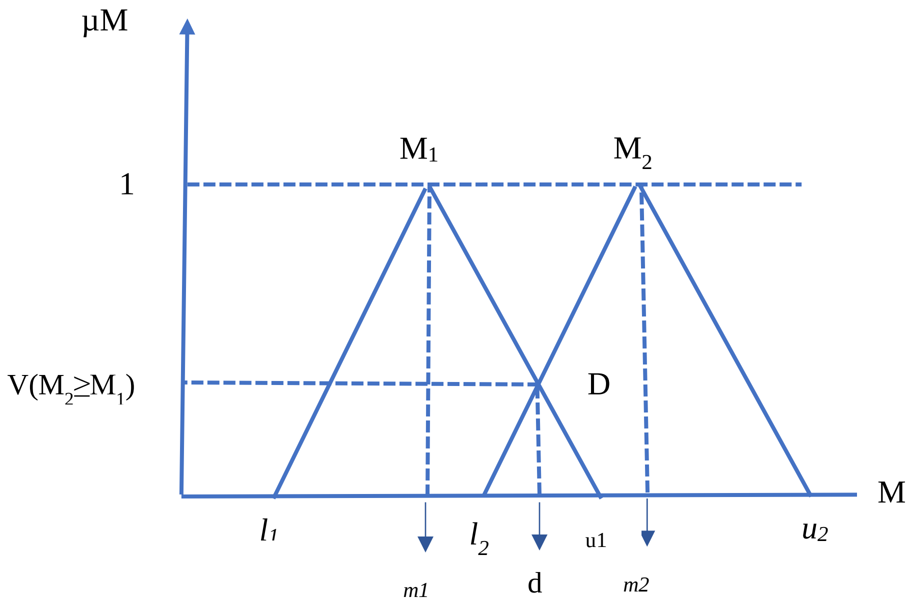


Figure 4.2 Degree of intersection between M_1 and M_2

Weight vector is given by:

$$W' = \left(d'(A_1), d'(A_2), \ldots\ldots, d'(A_n) \right)^T$$ (Eq. 4.7)

Where A_i are the n elements with i = 1 to n and

$$d'(A_i) = \min V(S_i \geq S_k)$$ (Eq. 4.8)

Weight vector W' is then normalised to get normalised weights. The normalised non-fuzzy number weight vector is given by:

$$W = (d(A_1), d(A_2), d(A_n))^T \quad \text{(Eq. 4.9)}$$

4.4 Hierarchical Model Building

The conceptual framework for measuring SC flexibility by (Pujawan, 2004) is found suitable and therefore selected as the basis for developing the hierarchical model. The model consists of four dimensions of flexibility with many contributing factors. These together contribute the performance measures used in this study and are listed at Table 4.1.

Table 4.1 List of Measures Used

SOURCING FLEXIBILITY (SF)	PRODUCT DEVELOPMENT FLEXIBILITY (PD)	PRODUCTION FLEXIBILITY (PR)	DELIVERY FLEXIBILITY (DF)
1. No. of qualified vendors (QV) 2. Cost of shifting a vendor (CV) 3. Reaction time of vendor (RV) 4. Response to emergency demand (RE)	1. Availability of project development team (AT) 2. Capability to develop new products (CP) 3. Software and other resources for product development (SR) 4. Availability of standard modules (AM)	1. Multiple production facilities (PF) 2. Skill of employees (SE) 3. Multipurpose production machinery (MM) 4. Low set up times (ST)	1. Availability of different modes of transportation (MT) 2. Variable speed of delivery (VD) 3. Product mix during transportation (PM)

First step in AHP is decomposing problem into a hierarchy of criteria and alternatives. A hierarchy is structured from top (primary objectives), then intermediate levels that are criteria to the lowest level, which is usually a list of alternatives from which to choose or compare. The hierarchical model is given at Figure 3.

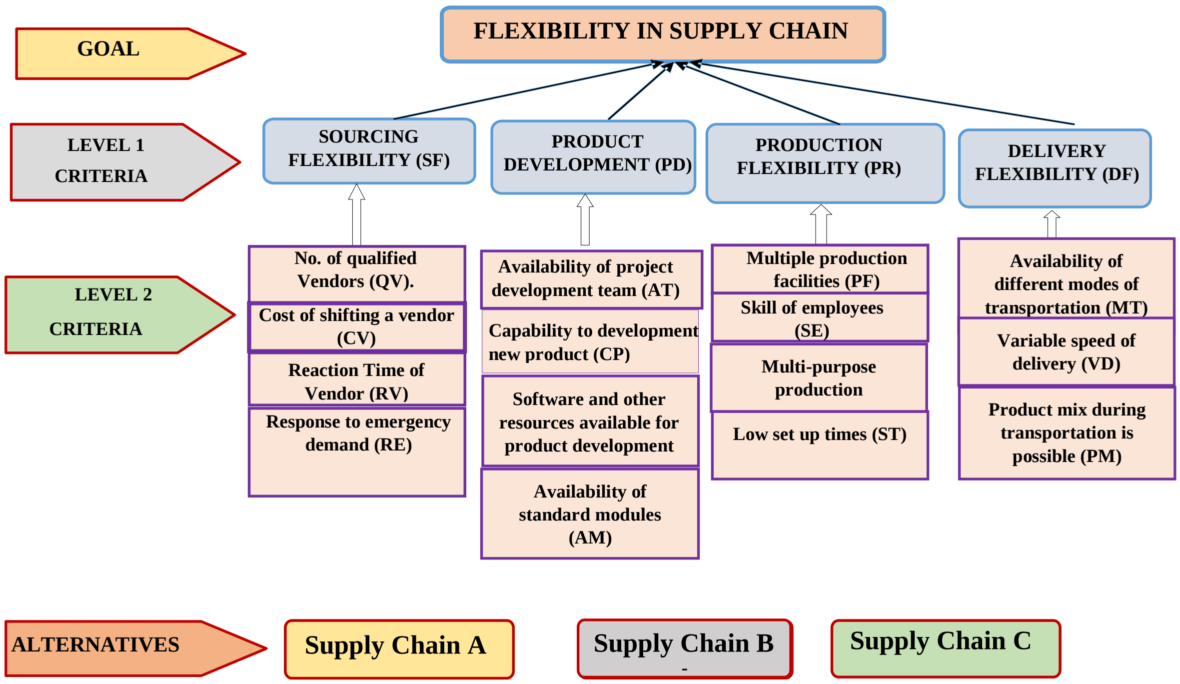


Figure 4.3 Hierarchical Model for Flexibility Measurement

4.5 Pair Wise Comparison

To perform a pair wise comparison among fuzzy parameters, linguistic variables have been defined for the criteria and sub criteria. The triangular fuzzy number of linguistic variables used in this study is given at Table 4.2 and same is figuratively represented at Figure 4.4.

Table 4.2 Triangular Fuzzy Number of Linguistic Variables

LINGUISTIC VARIABLE	TRIANGULAR FUZZY NUMBERS	RECIPROCAL TRIANGULAR FUZZY NUMBERS
Absolutely more important (AB)	(9,9,9)	(1/9,1/9,1/9)
Very strongly more important (VS)	(6,7,8)	(1/8,1/7,1/6)
Strongly more important (ST)	(4,5,6)	(1/6,1/5,1/4)
Weakly more important (WK)	(2,3,4)	(1/4,1/3,1/2)
Equally important (EQ)	(1,1,1)	(1,1,1)
Intermediate	(7,8,9), (5,6,7), (3,4,5), (1,2,3)	(1/9,1/8,1/7), (1/7,1/6,1/5), (1/5,1/4,1/3), (1/3,1/2,1)

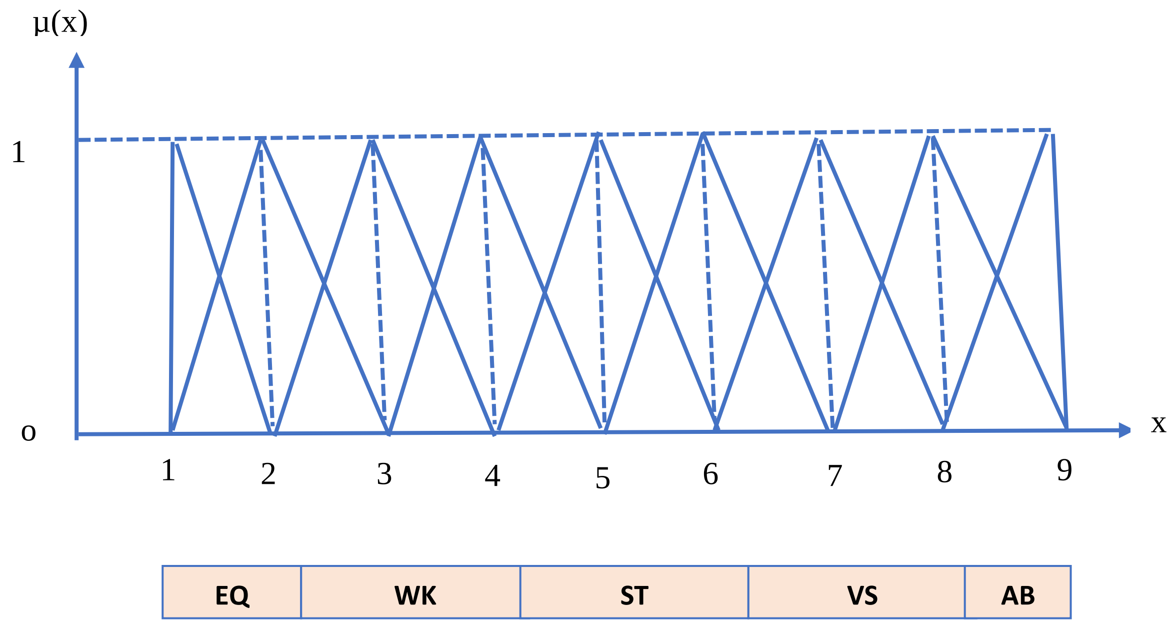


Figure 4.4 Triangular Fuzzy Numbers representing linguistic variables and levels of preference

4.6 Establishing Priorities and Determining Weights

Priorities are determined by paired comparison done by expert opinion. In this study, sample values are used to demonstrate the concept. Fuzzy analysis has been carried out using Multipurpose Fuzzy Measure and Fuzzy Integrals calculation software by CGI (available at: http://www.isc.senshu-u.ac.jp/~thc0456/Efuzzyweb/ fm31.html). The screen shot showing input for level 1 criterion is shown at Figure 4.5

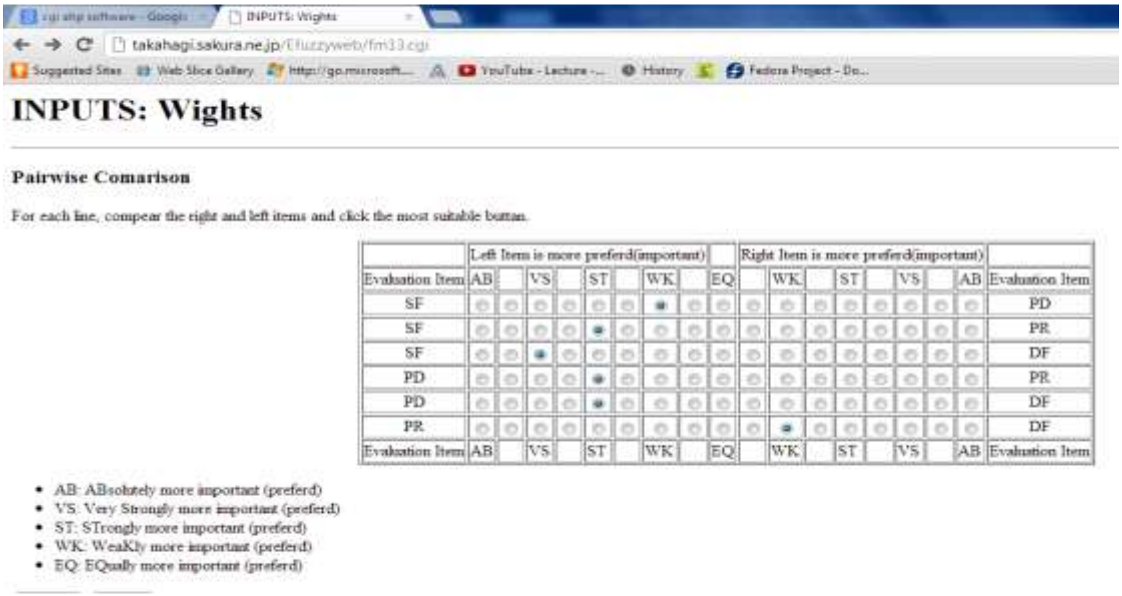


Figure 4.5 Screen Shot showing inputs for Level 1 criteria
(http://www.isc.senshu-u.ac.jp/~thc0456/ Efuzzyweb/ fm31.html)

The inputs are in linguistic form as mentioned at Table 4.2. CGI software calculates normalised weights based on fuzzy input. The weights obtained for level 1 criterion are given at Table 4.3.

Table 4.3 Weights at Level 1 Criteria Evaluation

Evaluation Items	Weights
Sourcing Flexibility (SF)	0.548288
Product Development Flexibility (PD)	0.296728
Production Flexibility (PR)	0.101833
Delivery Flexibility (DF)	0.0531505

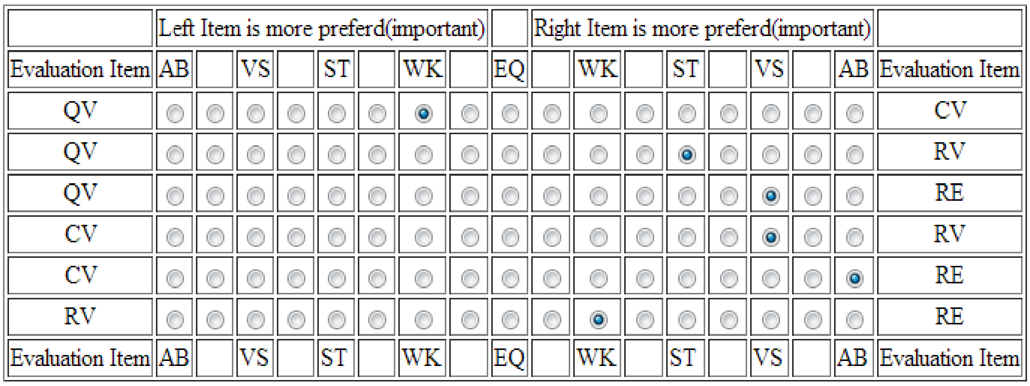
C.I.=0.0772054

In similar way, paired comparisons are done for each of level 2 criteria. The fuzzy input data screen and resulting weighted matrix for each level 2 criterion are shown at Table 4.4.

Table 4.4 Screen Shots showing inputs for Level 2 criteria and Resultant Weighted Matrix

SOURCING FLEXIBILITY (SF)

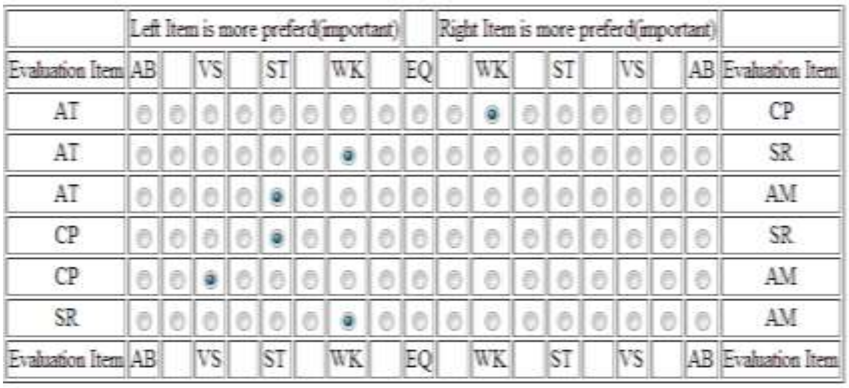
Fuzzy Input Screen Shot



	Left Item is more preferd(important)									Right Item is more preferd(important)								
Evaluation Item	AB		VS		ST		WK		EQ		WK		ST		VS		AB	Evaluation Item
QV							●											CV
QV													●					RV
QV															●			RE
CV															●			RV
CV																	●	RE
RV											●							RE
Evaluation Item	AB		VS		ST		WK		EQ		WK		ST		VS		AB	Evaluation Item

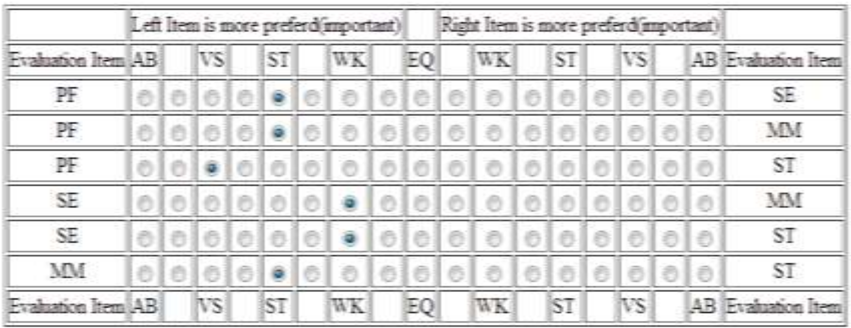
CRITERIA	WEIGHT
No. of qualified Vendors (QV)	0.0849321
Cost of shifting a vendor (CV)	0.0424831
Reaction Time of Vendor (RV)	0.28961
Response to emergency demand (RE)	0.582975
C.I.=0.0558325	

PRODUCT DEVELOPMENT FLEXIBILITY (PD)	
Fuzzy Input Screen Shot	



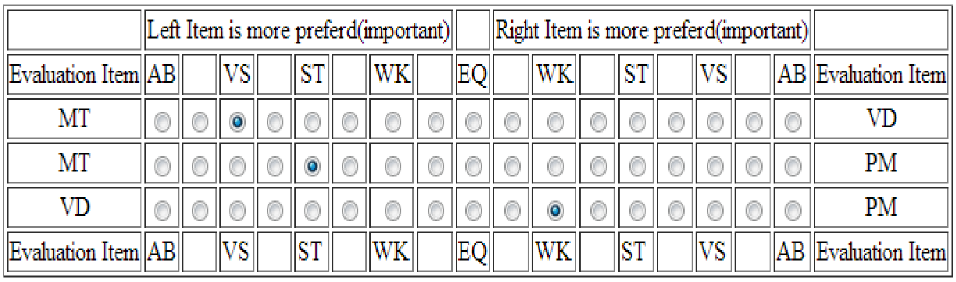
CRITERIA	WEIGHT
Availability of project development team (AT)	0.262229
Capability to development new product (CP)	0.564963
Software and resources for product development (SR)	0.117523
Availability of standard modules (AM)	0.055284
C.I.=0.039422	

PRODUCTION (PR)	
Fuzzy Input Screen Shot	



CRITERIA	WEIGHT
Multiple production facilities (PF)	0.608789
Skill of employees (SE)	0.202853
Multipurpose production machinery (MM)	0.13483
Low set up times (ST)	0.053528
C.I.=0.130992	

DELIVERY FLEXIBILITY (DF)
Fuzzy Input Screen Shot



	Left Item is more preferd(important)									Right Item is more preferd(important)							
Evaluation Item	AB		VS		ST		WK		EQ		WK		ST		VS		AB	Evaluation Item
MT	○	○	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	VD
MT	○	○	○	○	●	○	○	○	○	○	○	○	○	○	○	○	○	PM
VD	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	PM
Evaluation Item	AB		VS		ST		WK		EQ		WK		ST		VS		AB	Evaluation Item

CRITERIA	WEIGHT
Availability of different modes of transportation (MT)	0.730533
Variable speed of delivery (VD)	0.081012
Product mix during transportation (PM)	0.18845
C.I.=0.0311513	

The ‘weights obtained are then normalised. Summary of weights and normalised weights are given at Table 4.5.

Table 4.5 Summary of Weights obtained

LEVEL 1 CRITERIA		LEVEL 2 CRITERIA		
CRITERIA	**WEIGHT**	**CRITERIA**	**WEIGHT**	**NORMALISED GLOBAL WEIGHT**
Sourcing Flexibility (SF)	0.548288	No. of qualified Vendors (QV)	0.0849321	0.046567
		Cost of shifting a vendor (CV)	0.0424831	0.023293
		Reaction Time of Vendor (RV)	0.28961	0.15879
		Response to emergency demand (RE)	0.582975	0.319638
Product Development Flexibility (PD)	0.296728	Availability of project development team (AT)	0.262229	0.077811
		Capability to development new product (CP)	0.564963	0.16764

LEVEL 1 CRITERIA		LEVEL 2 CRITERIA		
CRITERIA	WEIGHT	CRITERIA	WEIGHT	NORMALISED GLOBAL WEIGHT
		Software and resources for product development (SR)	0.117523	0.034872
		Availability of standard modules (AM)	0.055284	0.016404
Production (PR)	0.101833	Multiple production facilities (PF)	0.608789	0.061995
		Skill of employees SE	0.202853	0.020657
		Multipurpose production machinery (MM)	0.13483	0.01373
		Low set up times (ST)	0.053528	0.005451
Delivery Flexibility (DF)	0.0531505	Availability of different modes of transportation (MT)	0.730533	0.038828
		Variable speed of delivery (VD)	0.081012	0.004306
		Product mix during transportation (PM)	0.18845	0.010016

4.7 Results and Discussion

The study demonstrates use of Fuzzy AHP for measurement of flexibility in SCs. Data used is of a hypothetical firm, therefore numerical value of result is unimportant. Significant contribution of this work is development of a method of integrated Performance Evaluation of Flexibility using tools such as Fuzzy AHP integrated with other performance measurement framework and demonstration of suggested framework using sample data set.

Normalised Priority Matrix (Table. 4.5) provides contribution of each criterion in achieving SC Flexibility. Decision makers can thus evaluate how each performance indicator will contribute in achieving flexibility goal and thus prioritise its resource deployment. Overall Performance Index can also be derived from this model based on performance measures obtained from SCs under observation. This quantified performance index helps in comparing flexibility similar to SCs, and performance of sub units of a SC. It also helps in comparing with earlier flexibility performances of same SC or sub unit. These measures can also be used for target setting and as a feedback for mid-course correction and monitoring.

4.8 Conclusion

This work presents various aspects of SC flexibility and its measurement. It is observed that there is good progress in the field of manufacturing flexibility and its measurement. However, measurement of flexibility in SC context is still in its infant stage and needs more attention. This study examines literature based on the measurement of flexibility in SC and its major contributions so far. Fuzzy AHP is a good tool to measure flexibility in a SC. The Proposed Fuzzy AHP method demonstrates how performance can be evaluated for a given SC.