Decision-making scenario towards Supply chain performance Assessment in Fuzzy Context

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Certificate of Approval

This is to certify that the thesis entitled *" Decision-making scenario towards Supply chain performance Assessment in Fuzzy Context"* submitted by *Pratik Das (109ME0366)* in partial fulfillment of the requirement for the award of Bachelor of Technology Degree in Mechanical Engineering at the National Institute of Technology, Rourkela (Deemed University) is a genuine work carried out under my supervision.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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Contents

List of Tables

List of Figures

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Abstract

Supply chain management (SCM) has been viewed as one of the most powerful tool for enhancing organizational competitiveness both in manufacturing as well as services. SCM often encounters a variety of decision-making situations. The process becomes complicated due to subjectivity of qualitative evaluation criterions/attributes. For proper understanding and controlling on key performance elements in a SCM and for successful implementation of SCM in an entire organizational context, supply chain performance extent need to be assessed. Supply chain performance appraisement is basically a multi-criteria decision-making (MCDM) process subjected to numerous evaluation indices, both qualitative as well as quantitative. Difficulty is faced in dealing with qualitative performance indices. This requires expert opinion to be obtained by an experienced decision-making group. In the real word, decision-making problems are very vague and uncertain in a number of ways. Expert data are often incomplete, imprecise as well as inconsistent. Most of the criteria being interdependent and having interactive features; data cannot be evaluated by conventional methods. Therefore, it requires exploration of the fuzzy multi-criteria decision making (FMCDM) tools and techniques. Fuzzy logic has the capability of efficiently dealing with vague human judgment; thereby, facilitating the said decision-making process. To this end, this paper describes development of a fuzzy decision support system (DSS) towards performance evaluation of an organizational supply chain. The research has been extended to identify ill-performing areas of the entire organizational supply chain, which require future improvement.

Chapter 1

Introduction

Supply chains comprise all activities associated with the flow and transformation of goods from the raw material stage through to the end user (Handfield and Nichols,[1]. A range of benefits has been attributed to supply chain management, including reduced costs, increased market share and sales, and solid customer relations (Ferguson, 2000).

Market globalization, intensifying competition and an increasing emphasis on customer orientation are regularly cited as catalyzing the surge in interest in supply chain management (e.g. Gunasekaran et al., 2001[2]; Webster, 2002[3]). Against this backdrop, effective supply chain management is treated as key to building a sustainable competitive edge through improved inter and intra-firm relationships (Ellinger, 2000[4]). In order to analyze the efficiency and benefits of SC scientifically and objectively, the performance evaluation system and method of SC should be established accordingly (Ma, 2005[5]).

In order to explore the extent of research in supply chain performance measurement and establish the gap in knowledge in supply chain performance measurement using fuzzy logic; the present work aims to develop an efficient DSS to facilitate supply chain performance appraisement in an organizational context. Empirical data has been analyzed for better understanding on the methodology of analysis towards estimating SC performance index.

Chapter 2

Literature Review

Beamon[6] (1999) provided an overview and evaluation of the performance measures used in supply chain models. The author presented a framework for the selection of performance measurement systems for manufacturing supply chains. The author also proposed a new flexibility measures for supply chains. Gunasekaran et al.[7] (2004) developed a framework to promote a better understanding of the importance of SCM performance measurement and metrics. Hervani et al.[8] (2005) provided an integrative framework for study, design and evaluation of green supply chain management performance tools.

Shepherd and Günter[9] (2006) provided taxonomy of performance measures followed by a critical evaluation of measurement systems designed to evaluate the performance of supply chains. Bhagwat and Sharma[10] (2007) developed a balanced scorecard for supply chain management (SCM) that measured and evaluated day-to-day business operations from following four perspectives: finance, customer, internal business process, and learning and growth. Varma et al.[11] (2008)used a combination of analytical hierarchy process (AHP) and balanced scorecard (BSC) for evaluating performance of the petroleum supply chain. Yang[12] (2009) analyzed the efficiency and benefits of supply chain (SC) scientifically and validated the usability of methods on performance evaluation index system.

Cai et al.[13] (2009) proposed a framework towards improving the iterative key performance indicators (KPIs) accomplishment in a supply chain context. The proposed framework quantitatively analyzed the interdependent relationships among a set of KPIs. It could identify crucial KPI accomplishment costs and proposed performance improvement strategies for decision-makers in a supply chain. Trkman, et al.[14] (2010) investigated the relationship between analytical capabilities in the plan, source, make and deliver area of the supply chain and its performance using information system support and business process orientation as moderators.

Chen and Yan[15] (2011) constructed an alternative network DEA model that embodied the internal structure for supply chain performance evaluation. Ip et al.[16] (2011) proposed an integrated approach towards modeling and measuring supply chain performance and stability using system dynamics (SD) and the autoregressive integrated moving average (ARIMA). Effectiveness and efficiency, with six corresponding indicators (product reliability, employee fulfillment, customer fulfillment, on-time delivery, profit growth, and working efficiency), were found to be the most significant factors in the performance of the supply chain.

Cho et al.[17] (2012) developed a framework of service supply chain performance measurement. Based on the strategic, tactical and operational level performance in a service supply chain, measures and metrics were discussed in this reporting. The emphasis was on performance measures dealing with service supply chain processes such as demand management, customer relationship management, supplier relationship management, capacity and resource management, service performance, information and technology management and service supply chain finance.

Elgazzar et al.[18] (2012) developed a performance measurement method which links supply chain (SC) processes' performance to a company's financial strategy through demonstrating and utilizing the relationship between SC processes' performance and a company's financial performance. Olugu and Wong[19] (2012) developed an expert fuzzy rule-based system for closed-loop supply chain performance assessment in the automotive industry. Uysal[20] (2012) applied the Decision Making Trial and Evaluation Laboratory (DEMATEL) Method to deal with the importance and causal relationships between the sustainable performances measurements criteria by considering the interrelationships among them.

Vaidya and Hudnurkar[21] (2013) proposed an approach to evaluate the performance of supply chain using multiple criteria. A multi-criteria decision making tool (like analytic hierarchy process) was developed for performance evaluation. The said methodology was also elucidated with an illustration and a case from Indian chemical company. Supply chain performance number was computed, indicating the present performance status of the supply chain. The methodology also helped rank the various links according to its performance. The analysis proposed on computation of supply chain performance number (SCPN).

According to (Gunasekaran et al.[7], 2004), the literature on SCM focus strategies and technologies for effectively managing a supply chain is quite vast. In recent years, organizational performance measurement and metrics have received much attention from researchers and practitioners. The role of these measures and metrics in the success of an organization cannot be overstated because they affect strategic, tactical and operational planning and control. Performance measurement and metrics have an important role to play in setting objectives, evaluating performance, and determining future courses of actions. Performance measurement and metrics pertaining to SCM have not received adequate attention from researchers or practitioners.

Issues related to performance assessment and related aspects have been attempted by pioneer researchers to a remarkable extent. Different SC performance evaluation index systems have been documented in literature. It has been found that in most of the cases, SC performance evaluation criteria/attribute hierarchy consists of a variety of subjective evaluation indices. Subjective attributes are difficult to analyze due to the incompleteness as well as inconsistency in the evaluation information. Expert opinions are often expressed in linguistic variables which are basically vague in nature. Unless and until linguistic data are transformed into a mathematic base, it is difficult to analyze. Conceptually, SC performance indicates existence of an evaluation index to be represented by a number. Such evaluation or appraisement index can be treated as an indicator to reflect existing SC performance extent; basis for comparing performance of different organizations (running under similar SC architecture i.e. benchmarking).

Chapter 3

Fuzzy Preliminaries

To deal with vagueness in human thought, Zadeh first introduced the fuzzy set theory, which has the capability to represent/manipulate data and information possessing based on non-statistical uncertainties. Moreover fuzzy set theory has been designed to mathematically represent uncertainty and vagueness and to provide formalized tools for dealing with the imprecision inherent to decision making problems. Some basic definitions of fuzzy sets, fuzzy numbers and linguistic variables are reviewed from Zadeh[22][23][24] (1965, 1975), Buckley[25] (1985), Negi[26] (1989), Kaufmann and Gupta[27] (1991). The basic definitions and notations below will be used throughout this thesis until otherwise stated.

3.1 Definitions of fuzzy sets

Definition 3.1.1. A fuzzy set $\tilde{A}$ in a universe of discourse X is characterised by a membership function $\mu_{\tilde{A}}(x)$ which associates with each element x in X a real number in the interval [0,1]. The function value $\mu_{\tilde{A}}(x)$ is termed the grade of membership of x in $\tilde{A}$ (Kaufmann and Gupta[27], 1991).

Definition 3.1.2. A fuzzy set $\tilde{A}$ in a universe of discourse X is convex if and only if

$$\mu_{\tilde{A}}(\lambda x_1 + (1-\lambda)x_2) \geq min(\mu_{\tilde{A}}(x_1), \mu_{\tilde{A}}(x_2)) \tag{3.1}$$

For all x_1, x_2 in X and all $\lambda \in [0,1]$, where min denotes the minimum operator (Klir and Yuan[28], 1995).

Definition 3.1.3. The height of a fuzzy set is the largest membership grade attained by any element in that set. A fuzzy set $\tilde{A}$ in the universe of discourse X is called normalized when the height of $\tilde{A}$ is equal to 1 (Klir and Yuan[28], 1995).

3.2 Definitions of fuzzy numbers

Definition 3.2.1. A fuzzy number is a fuzzy subset in the universe of discourse X that is both convex and normal. Fig. 3.1 shows a fuzzy number $\tilde{n}$ in the universe of discourse X that conforms to this definition (Kaufmann and Gupta[27], 1991).

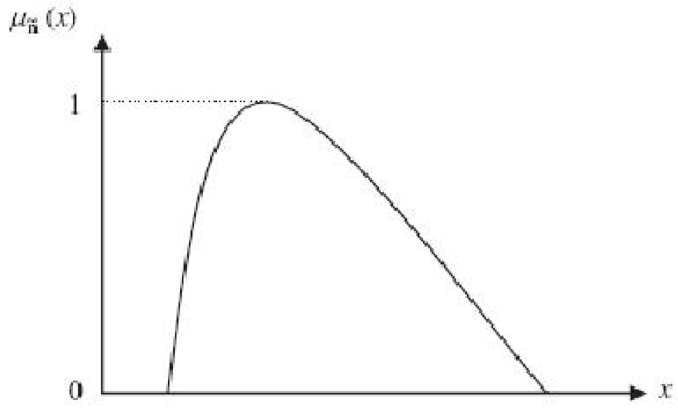

Figure 3.1: A Fuzzy Number $\tilde{n}$

Definition 3.2.2. The α-cut of fuzzy number $\tilde{n}$ is defined as:

$$\tilde{n}^{\alpha} = \{x_i : \mu_{\tilde{n}}(x_i) \geq \alpha, x_i \in X\} \tag{3.2}$$

Here, $\alpha \in [0, 1]$.

The symbol $\tilde{n}^{\alpha}$ represents a non-empty bounded interval contained in X, which can be denoted by $\tilde{n}^{\alpha} = [n_l^{\alpha}, n_u^{\alpha}]$, n_l^{α} and n_u^{α}, are the lower and upper bounds of the closed interval, respectively (Kaufmann and Gupta[27], 1991; Zimmermann[29], 1991). For a fuzzy number $\tilde{n}$, if $n_l^{\alpha} > 0$ and $n_u^{\alpha} \leq 1$ for all $\alpha \in [0, 1]$, then $\tilde{n}$ is called a standardized (normalized) positive fuzzy number (Negi[26], 1989)

Definition 3.2.3. Suppose, a positive triangular fuzzy number (PTFN) is $\tilde{A}$ and that can be defined as (a, b, c) shown in Fig. 2. The membership function $\mu_{\tilde{n}}(x)$ is defined as:

$$\mu_{\tilde{n}}(x) = |x| = \begin{cases} (x-a)/(b-a), & \text{if } a \leq x \leq b, \\ (c-x)/(c-b), & \text{if } b \leq x \leq c, \\ 0, & \text{otherwise,} \end{cases} \tag{3.3}$$

Based on extension principle, the fuzzy sum $\oplus$ and fuzzy subtraction $\ominus$ of any two triangular fuzzy numbers are also triangular fuzzy numbers; but the multiplication $\otimes$ of any two triangular fuzzy numbers is only approximate triangular fuzzy number (Zadeh[23][24], 1975). Let's have a two positive triangular fuzzy numbers, such as $\tilde{A}_1 = (a_1, b_1, c_1)$, and $\tilde{A}_2 = (a_2, b_2, c_2)$, and a positive real number $r = (r, r, r)$, some algebraic operations can be expressed as follows:

$$\tilde{A}_1 \oplus \tilde{A}_2 = (a_1 + a_2, b_1 + b_2, c_1 + c_2), \tag{3.4}$$

$$\tilde{A}_1 \ominus \tilde{A}_2 = (a_1 - a_2, b_1 - b_2, c_1 - c_2), \tag{3.5}$$

$$\tilde{A}_1 \otimes \tilde{A}_2 = (a_1 a_2, b_1 b_2, c_1 c_2), \tag{3.6}$$

$$r \otimes \tilde{A}_1 = (ra_1, ra_2, ra_3), \tag{3.7}$$

$$\tilde{A}_1 \oslash \tilde{A}_2 = (a_1/c_1, b_1/b_2, c_1/a_2), \tag{3.8}$$

the operators $\vee(max)$ and $\wedge(min)$ are defined as:

$$\tilde{A}_1(\vee)\tilde{A}_2 = (a_1 \vee a_2, b_1 \vee b_2, c_1 \vee c_2) \tag{3.9}$$

$$\tilde{A}_1(\wedge)\tilde{A}_2 = (a_1 \wedge a_2, b_1 \wedge b_2, c_1 \wedge c_2) \tag{3.10}$$

Here, $r > 0$, and $a_1, b_1, c_1 > 0$ Also the crisp value of triangular fuzzy number set $\tilde{A}_1$ can be determined by defuzzification which locates the Best Non-fuzzy Performance (BNP) value. Thus, the BNP values of fuzzy number are calculated by using the center of area (COA) method as follows: (Moeinzadeh and Hajfathaliha[30], 2010)

$$BNP_i = \frac{[(c-a)+(b-a)]}{3} + a, \qquad \forall i, \tag{3.11}$$

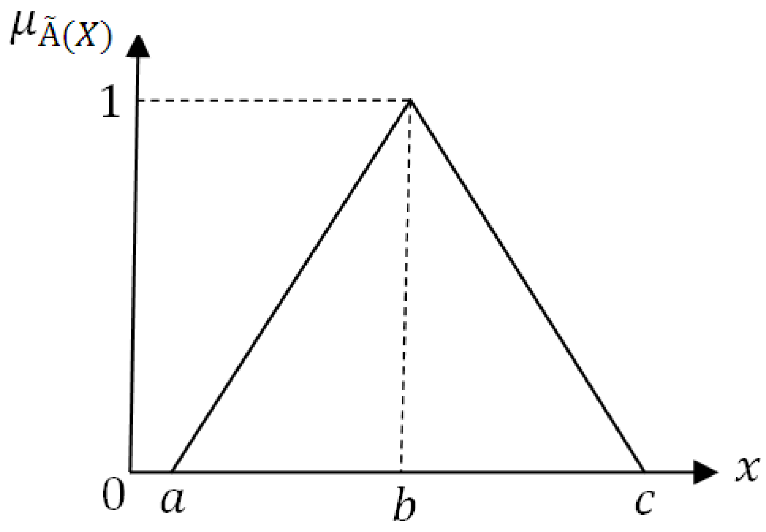

Figure 3.2: A Triangular Fuzzy Number $\tilde{A}$

Definition 3.2.4. A matrix $\tilde{D}$ is called a fuzzy matrix if at least one element is a fuzzy number (Buckley[25], 1985).

3.3 Linguistic Variable

Definition 3.3.1. A linguistic variable is the variable whose values are not expressed in numbers but words or sentences in a natural or artificial language, i.e., in terms of linguistic (Zadeh[23][24], 1975). The concept of a linguistic variable is very useful in dealing with situations which are so complex or not too well defined to be reasonably described in conventional quantitative expressions (Zimmermann[29], 1991). For example, 'weight' is a linguistic variable whose values are 'very low', 'low', 'medium', 'high', 'very high', etc. Fuzzy numbers can also represent these linguistic values.

3.4 The Concept of Generalized Trapezoidal Fuzzy Numbers

By the definition given by (Chen[31], 1985), a generalized trapezoidal fuzzy number can be defined as $\tilde{A} = (a_1, a_2, a_3, a_4; w_{\tilde{A}})$ as shown in Fig. 3.3. and the membership function

$\mu_{\tilde{A}}(x) : R \mapsto [0, 1]$ is defined as follows:

$$\mu = \begin{cases} \frac{x-a}{x-b} \times w_{\tilde{A}}, & x \in (a_1, a_2) \\ w_{\tilde{A}}, & x \in (a_2, a_3) \\ \frac{x-a_4}{a_3-a_4} \times w_{\tilde{A}}, & x \in (a_3, a_4) \\ 0, & x \in (-\infty, a_1) \cup (a_4, \infty) \end{cases} \tag{3.12}$$

Here, $a_1 \leq a_2 \leq a_3 \leq a_4$ and $w_{\tilde{A}} \in [0, 1]$

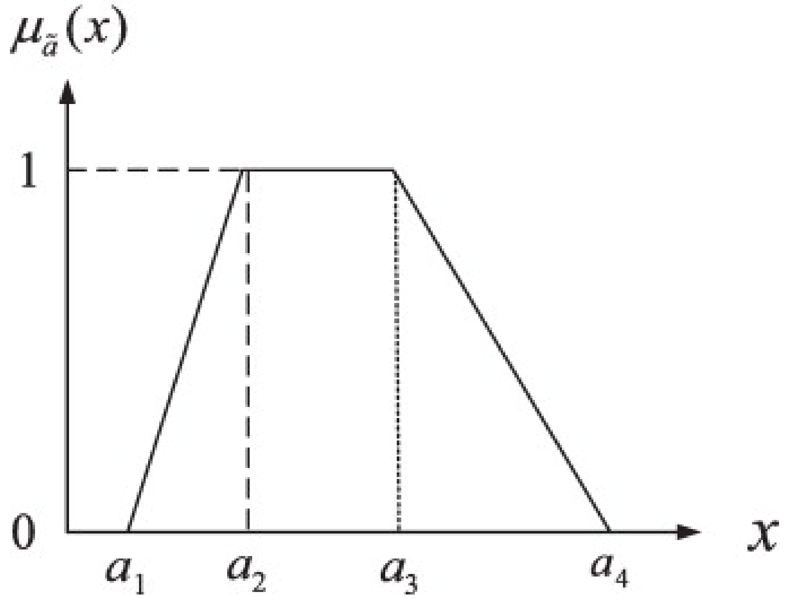

Figure 3.3: A Trapezoidal Fuzzy Number $\tilde{A}$

The elements of the generalized trapezoidal fuzzy numbers $x \in R$ are real numbers, and its membership function $\mu_{\tilde{A}}(x)$ is the regularly and continuous convex function, it shows that the membership degree to the fuzzy sets. If $-1 \leq a_1 \leq a_2 \leq a_3 \leq a_4 \leq 1$ then $\tilde{A}$ is called the normalized trapezoidal fuzzy number. Especially, if $w_{\tilde{A}} = 1$ then $\tilde{A}$ is called trapezoidal fuzzy number (a_1, a_2, a_3, a_4); if $a_1 < a_2 = a_3 < a_4$, then $\tilde{A}$ is reduced to a triangular fuzzy number. If $a_1 = a_2 = a_3 = a_4$, then $\tilde{A}$ is reduced to a real number. Suppose that $\tilde{a} = (a_1, a_2, a_3, a_4; w_{\tilde{a}})$ and $\tilde{b} = (b_1, b_2, b_3, b_4; w_{\tilde{b}})$ are two generalized trapezoidal fuzzy numbers, then the operational rules of the generalized trapezoidal fuzzy numbers $\tilde{a}$ and $\tilde{b}$ are shown as follows (Chen and Chen[32], 2009):

$$\begin{aligned} \tilde{a} \oplus \tilde{b} &= (a_1, a_2, a_3, a_4; w_{\tilde{a}}) \oplus (b_1, b_2, b_3, b_4; w_{\tilde{b}}) \\ &= (a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4; min(w_{\tilde{a}}, w_{\tilde{b}})) \end{aligned} \tag{3.13}$$

$$\begin{aligned} \tilde{a} \ominus \tilde{b} &= (a_1, a_2, a_3, a_4; w_{\tilde{a}}) \ominus (b_1, b_2, b_3, b_4; w_{\tilde{b}}) \\ &= (a_1 - b_1, a_2 - b_2, a_3 - b_3, a_4 - b_4; min(w_{\tilde{a}}, w_{\tilde{b}})) \end{aligned} \tag{3.14}$$

$$\begin{aligned} \tilde{a} \otimes \tilde{b} &= (a_1, a_2, a_3, a_4; w_{\tilde{a}}) \otimes (b_1, b_2, b_3, b_4; w_{\tilde{b}}) \\ &= (a_1 - b_1, a_2 - b_2, a_3 - b_3, a_4 - b_4; min(w_{\tilde{a}}, w_{\tilde{b}})) \end{aligned} \tag{3.15}$$

Here,

$$\begin{aligned}
a &= min(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4) \\
b &= min(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3) \\
c &= max(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3) \\
d &= max(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4)
\end{aligned}$$

If $a_1, a_2, a_3, a_4, b_1, b_2, b_3, b_4$ are real numbers, then

$$\tilde{a} \otimes \tilde{b} = (a_1 \times b_1, a_2 \times b_2, a_3 \times b_3, a_4 \times b_4; min(w_{\tilde{a}}, w_{\tilde{b}}))$$

$$\begin{aligned}
\tilde{a} \oslash \tilde{b} &= (a_1, a_2, a_3, a_4; w_{\tilde{a}}) \oslash (b_1, b_2, b_3, b_4; w_{\tilde{b}}) \\
&= (a_1 - b_4, a_2 - b_3, a_3 - b_2, a_4 - b_1; min(w_{\tilde{a}}, w_{\tilde{b}}))
\end{aligned} \tag{3.16}$$

Chen and Chen[33] (2003) proposed the concept of COG point of generalized trapezoidal fuzzy numbers, and suppose that the COG point of the generalized trapezoidal fuzzy number $\tilde{a} = (a_1, a_2, a_3, a_4; w_{\tilde{a}})$ is $(x_{\tilde{a}}, y_{\tilde{a}})$ then:

$$y_{\tilde{a}} = \begin{cases} \frac{w_{\tilde{a}} \times \frac{a_3 - a_2}{a_4 - a_1} + 2}{6}, & if\ a_1 \neq a_4 \\ \frac{w_{\tilde{a}}}{2}, & if\ a_1 = a_4 \end{cases} \tag{3.17}$$

$$x_{\tilde{a}} = \frac{y_{\tilde{a}} \times (a_2 + a_3) + (a_3 + a_4) \times (w_{\tilde{a}} - y_{\tilde{a}})}{2 \times w_{\tilde{a}}} \tag{3.18}$$

Fig. 4. Trapezoidal Fuzzy Number [Thorani et al. (2012)]

3.5 Ranking of Generalized Trapezoidal Fuzzy Numbers [Thorani et al.[34] (2012)]

The centroid of a trapezoid is considered as the balancing point of the trapezoid (Fig. 3.4). Divide the trapezoid into three plane figures. These three plane figures are a triangle (APB), a rectangle (BPQC), and a triangle (CQD), respectively. Let the centroids of the three plane figures be G1, G2, and G3 respectively. The Incenter of these Centroids G1, G2 and G3 is taken as the point of reference to define the ranking of generalized trapezoidal fuzzy numbers. The reason for selecting this point as a point of reference is that each centroid point are balancing points of each individual plane figure, and the Incentre of these Centroid points is a much more balancing point for a generalized trapezoidal fuzzy number. Therefore, this point would be a better reference point than the Centroid point of the trapezoid. Consider a generalized trapezoidal fuzzy number $\tilde{A} = (a, b, c, d; w)$,(Fig. 1). The Centroids of the three plane figures are

$$G_1 = \left(\frac{a + 2b}{3}, \frac{w}{3}\right), G_2 = \left(\frac{b + c}{2}, \frac{w}{2}\right) \text{and} G_3 = \left(\frac{2c + d}{3}, \frac{w}{3}\right)$$

respectively. Equation of the line $\overline{G_1 G_3}$ is $y = \frac{w}{3}$ and G_2 does not lie on the line $\overline{G_1 G_3}$. Therefore, G_1, G_2 and G_3 are non-collinear and they form a triangle. We define the Incentre $I_{\tilde{A}}(\overline{x_0}, \overline{y_0})$ of the triangle with vertices G_1, G_2 and G_3 of the generalized trapezoidal fuzzy number $\tilde{A} = (a, b, c, d; w)$as

$$I_{\tilde{A}}(\overline{x_0}, \overline{y_0}) = \left(\frac{\alpha\left(\frac{a+2b}{3}\right) + \beta\left(\frac{b+c}{2}\right) + \gamma\left(\frac{2c+d}{3}\right)}{\alpha+\beta+\gamma}, \frac{\alpha\left(\frac{w}{3}\right) + \beta\left(\frac{w}{2}\right) + \gamma\left(\frac{w}{3}\right)}{\alpha+\beta+\gamma}, \right) \tag{3.19}$$

Here,

$$\alpha = \frac{\sqrt{(c-3b+2d)^2 + w^2}}{6}$$
$$\beta = \frac{\sqrt{(2c+d-a-2b)^2}}{3}$$
$$\gamma = \frac{\sqrt{(3c-2a-b)^2 + w^2}}{6}$$

As a special case, for triangular fuzzy number $\tilde{A} = (a, b, c, d; w)$ i.e.the incentre of Centroids is $c = b$ given by

$$I_{\tilde{A}}(\overline{x_0}, \overline{y_0}) = \left(\frac{x\left(\frac{a+2b}{3}\right) + yb + z\left(\frac{2b+d}{3}\right)}{x+y+z}, \frac{x\left(\frac{w}{3}\right) + y\left(\frac{w}{2}\right) + y\left(\frac{w}{3}\right)}{x+y+z}, \right) \tag{3.20}$$

Here,

$$x = \frac{\sqrt{(2d-2b)^2 + w^2}}{6}$$
$$y = \frac{\sqrt{(d-a)^2}}{3}$$
$$z = \frac{\sqrt{(2b-2a)^2 + w^2}}{6}$$

The ranking function of the generalized trapezoidal fuzzy numberwhich maps the set of all fuzzy numbers to a set of real numbers is denied as,

$$\begin{aligned} R(\tilde{A}) &= x_0 \times y_0 \\ &= \left(\frac{x\left(\frac{a+2b}{3}\right) + yb + z\left(\frac{2b+d}{3}\right)}{x+y+z}, \frac{x\left(\frac{w}{3}\right) + y\left(\frac{w}{2}\right) + y\left(\frac{w}{3}\right)}{x+y+z}, \right) \end{aligned} \tag{3.21}$$

This is the Area between the incenter of the centroids $I_{\tilde{A}}(\overline{x_0}, \overline{y_0})$ as denied in Eq. and the original point. The Mode (m) of the generalized trapezoidal fuzzy number $\tilde{A} = (a, b, c, d; w)$ is defined as:

$$m = \frac{1}{2}\int_0^w (b+c)dx = \frac{w}{2}(b+c) \tag{3.22}$$

The Spread(s) of the generalized trapezoidal fuzzy number $\tilde{A} = (a, b, c, d; w)$ is defined as:

$$s = \int_0^w (d-a)dx = w(d-a) \tag{3.23}$$

The left spread (ls) of the generalized trapezoidal fuzzy number $\tilde{A} = (a, b, c, d; w)$ is defined as:

$$ls = \int_0^w (b - a)dx = w(b - a) \tag{3.24}$$

The right (rs) spread of the generalized trapezoidal fuzzy number $\tilde{A} = (a, b, c, d; w)$ is defined as:

$$rs = \int_0^w (d - c)dx = w(d - c) \tag{3.25}$$

Using the above definitions we now define the ranking procedure of two generalized trapezoidal fuzzy numbers. Let $\tilde{A} = (a_1, a_2, a_3, a_4; w_{\tilde{A}})$ and $\tilde{B} = (b_1, b_2, b_3, b_4; w_{\tilde{B}})$ be two generalized trapezoidal fuzzy numbers. The working procedure to compare $\tilde{A}$ and $\tilde{B}$ is as follows:
Step 1: Find $R(\tilde{A})$ and $R(\tilde{B})$
Case (i) If $R(\tilde{A}) < R(\tilde{B})$ then $\tilde{A} < \tilde{B}$
Case (ii) If $R(\tilde{A}) > R(\tilde{B})$then $\tilde{A} > \tilde{B}$
Case (iii) If $R(\tilde{A}) = R(\tilde{B})$,comparison is not possible, then go to step 2.
Step 2: Find $m(\tilde{A})$ and $m(\tilde{B})$
Case (i) If $m(\tilde{A}) < m(\tilde{B})$ then $\tilde{A} < \tilde{B}$
Case (ii) If $m(\tilde{A}) > m(\tilde{B})$ then $\tilde{A} > \tilde{B}$
Case (iii) If $m(\tilde{A}) = m(\tilde{B})$,comparison is not possible, then go to step 3.
Step 3: Find $s(\tilde{A})$ and $s(\tilde{B})$
Case (i) If $s(\tilde{A}) > s(\tilde{B})$ then $\tilde{A} < \tilde{B}$
Case (ii) If $s(\tilde{A}) < s(\tilde{B})$ then $\tilde{A} > \tilde{B}$
Case (iii) If $s(\tilde{A}) = s(\tilde{B})$,comparison is not possible, then go to step 4.
Step 4: Find $ls(\tilde{A})$ and $ls(\tilde{B})$
Case (i) If $ls(\tilde{A}) < ls(\tilde{B})$ then $\tilde{A} < \tilde{B}$
Case (ii) If $ls(\tilde{A}) > ls(\tilde{B})$ then $\tilde{A} > \tilde{B}$
Case (iii) If $ls(\tilde{A}) = ls(\tilde{B})$,comparison is not possible, then go to step 5.
Step 5: Examine $w_{\tilde{A}}$ and $w_{\tilde{B}}$
Case (i) If $w_{\tilde{A}} > w_{\tilde{B}}$ then $\tilde{A} > \tilde{B}$
Case (ii) If $w_{\tilde{A}} < w_{\tilde{B}}$ then $\tilde{A} < \tilde{B}$
Case (iii) If $w_{\tilde{A}} = w_{\tilde{B}}$ then $\tilde{A} \approx \tilde{B}$

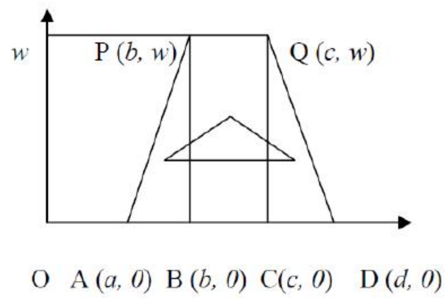

Figure 3.4: A Trapezoidal Fuzzy Number $\tilde{n}$

Chapter 4

Procedural Hierarchy of Supply Chain Performance Appraisement

A fuzzy based performance appraisement module proposed in this paper has been presented below. It utilizes the concept of Generalized Triangular Fuzzy Numbers (GTFNs) set. General Hierarchy Criteria (GHC) for evaluating supply chain performance extent generally involves various criterions as well as sub-criterions at different levels. Let us assume that GHC consists of two-level index system; which aims at achieving the target to evaluate overall appraisement index (Table 4.1). Tables 4.2-4.3 represent seven-member linguistic terms (and their corresponding generalized triangular fuzzy numbers) for analyzing decision-making information (attribute weights as well as appropriateness rating). 1st level consists of eight main criterions (C1, C2, C3, C4, C5, C6, C7, C8): Customer Service, Purchasing Management, Administration/Financial Management, Process, Cross Functional Measures, Manufacturing Management, Marketing Management, Extended Enterprise Measures, Logistics Performance.

Table 4.1: Evaluation Index System of Supply Chain Performance

Goal	1st level indices (Attributes)	2nd level indices (Criterions)
FPI, C	Customer Service, C1	Order Fill Rate, C11
		Line Item Fill Rate, C12
		Quantity Fill Rate, C13
		Backorders/Stock outs, C14
		Customer Satisfaction, C15
		%Resolution of first customer call, C16
		Customer Returns, C17
		Order Track and Trace Performance, C18
		Customer Disputes, C19
		Order Entry Accuracy, C1,10
		Order Entry Times, C1,11
	Purchasing Management, C2	Material Inventories, C21
		Supplier Delivery Performance, C22

Continued on next page

Table 4.1 – continued from previous page

Goal	1st level indices (Attributes)	2nd level indices (Criterions)
		Material/Component Quality, C23
		Material Stock Outs, C24
		Unit Purchase Costs, C25
		Material Acquisition Costs, C26
		Expediting Activities, C27
	Financial Management, C3	Cash Flow, C31
		Revenue, C32
		Return on Capital Employed, C33
		Cash-to-Cash Cycle, C34
		Return on Investment, C35
		Revenue Per Employee, C36
		Invoice Errors, C37
		Return on Assets, C38
	Cross Functional Measures, C4	Forecast Accuracy, C41
		Percent Perfect Orders, C42
		New Product-Time-To-Market, C43
		New Product-Time-To-First-Make, C44
		Planning Process Cycle Time, C45
		Schedule Changes, C46
	Manufacturing Management, C5	Product Quality, C51
		WIP Inventories, C52
		Adherence to Schedule, C53
		Cost Per Unit Produced, C54
		Setups/Changeovers, C55
		Setup/Changeover Costs, C56
		Unplanned Stockroom Issues, C57
		Bill-of-Materials Accuracy, C58
		Routing Accuracy, C59
		Plant Space Utilization, C5,10
		Line Breakdowns, C5,11
		Warranty Costs, C5,12
		Source-to-make-Cycle Time, C5,13
		Percent Scrap/Rework, C5,14
		Material Usage Variance, C5,15
		Overtime Usage, C5,16
		Production Cycle Time, C5,17
		Manufacturing Productivity, C5,18
		Master Schedule Stability, C5,19
	Marketing Management, C6	Market Share, C61
		Percent of Sales from New Products, C62
		Time-To-Market, C63
		Repeat versus New Customer Sales, C64

Continued on next page

Table 4.1 – continued from previous page

Goal	1st level indices (Attributes)	2nd level indices (Criterions)
	Extended Enterprise Measures, C7	
		Total Landed Cost, C71
		Point of Consumption Product Availability, C72
		Total Supply Chain Inventory, C73
		Retail Shelf Display, C74
		Channel Inventories, C75
		EDI Transactions, C76
		Percent of Demand/Supply on VMI/CRP, C77
		Percent of Customers Sharing Forecasts, C78
		Percent of Suppliers Getting Shared Forecast, C79
		Supplier Inventories, C7,10
		Internet Activity to Suppliers/Customers, C7,11
		Percent Automated Tendering, C7,12
	Logistics Performance, C8	Finished Goods Inventory Turns, C81
		Finished Goods Inventory Days of Supply, C82
		On-Time Delivery, C83
		Lines Picked/Hour, C84
		Damaged Shipments, C85
		Inventory Accuracy, C86
		Pick Accuracy, C87
		Logistics Cost, C88
		Shipment Accuracy, C89
		On-Time Shipment, C8,10
		Delivery Times, C8,11
		Warehouse Space Utilization, C8,12
		End-of-Life Inventory, C8,13
		Obsolete Inventory, C8,14
		Inventory Shrinkage, C8,15
		Cost of Carrying/Holding Inventory, C8,16
		Documentation Accuracy, C8,17
		Transportation Cost, C8,18
		Warehousing Costs, C8,19
		Container Utilization, C8,20
		Truck Cube Utilization, C8,21
		In-Transit Inventories, C8,22
		Premium Freight Charges, C8,23
		Warehouse Receipts, C8,24

Table 4.2: The Scale of Attribute Weights

Scale	$\otimes w$
Very Low (VL)	(0, 0.05, 0.15)
Low (L)	(0.1, 0.2, 0.3)
Medium Low (ML)	(0.2, 0.35, 0.5)
Medium (M)	(0.3, 0.5, 0.7)
Medium High (MH)	(0.5, 0.65, 0.8)
High (H)	(0.7, 0.8, 0.9)
Very High (VH)	(0.85, 0.95, 1.0)

Table 4.3: The Scale of Attribute Ratings

Scale	$\otimes w$
Very Poor (VP)	(0, 0.05, 0.15)
Poor (P)	(0.1, 0.2, 0.3)
Medium Poor (MP)	(0.2, 0.35, 0.5)
Medium (M)	(0.3, 0.5, 0.7)
Medium Good (MG)	(0.5, 0.65, 0.8)
Good (G)	(0.7, 0.8, 0.9)
Very Good (VG)	(0.85, 0.95, 1.0)

Table 4.4: Appropriateness rating (in linguistic scale) of 2^{nd} level indices assigned by DMs

2nd level indices	**Appropriateness rating (in linguistic scale) of 2^{nd} level indices assigned by DMs**				
	DM1	**DM2**	**DM3**	**DM4**	**DM5**
C_{11}	MP	MP	MP	P	MP
C_{12}	M	M	M	M	M
C_{13}	MG	MG	G	MG	MG
C_{14}	G	MG	G	G	G
C_{15}	MP	M	MG	MG	MG
C_{16}	G	G	G	G	MG
C_{17}	G	G	G	G	G
C_{18}	VG	G	VG	G	G
C_{19}	G	G	G	G	G
$C_{1,10}$	P	MP	MP	P	MP
$C_{1,11}$	M	M	M	M	M
C_{21}	G	MG	G	MG	MG
C_{22}	G	G	G	G	G
C_{23}	MP	M	MG	MG	G
C_{24}	G	G	G	G	MG
C_{25}	G	G	G	G	G
C_{26}	VG	G	VG	G	G
C_{27}	MP	MP	MP	P	P
C_{31}	G	VG	G	G	VG

Continued on next page

Table 4.4 – continued from previous page

2nd level indices	Appropriateness rating (in linguistic scale) of 2^{nd} level indices assigned by DMs				
	DM1	**DM2**	**DM3**	**DM4**	**DM5**
C_{32}	MP	MP	P	P	MP
C_{33}	M	M	M	M	M
C_{34}	G	G	G	MG	MG
C_{35}	G	G	G	G	G
C_{36}	MP	M	G	MG	G
C_{37}	G	G	G	G	MG
C_{38}	G	G	G	G	G
C_{41}	VG	G	VG	G	G
C_{42}	MP	P	MP	P	P
C_{43}	G	G	VG	G	G
C_{44}	G	G	G	G	G
C_{45}	P	P	MP	P	MP
C_{46}	M	M	M	M	M
C_{51}	G	MG	G	MG	MG
C_{52}	G	G	G	G	G
C_{53}	MP	M	MG	MG	G
C_{54}	G	G	G	G	MG
C_{55}	G	G	G	G	G
C_{56}	VG	G	G	G	G
C_{57}	MP	MP	P	P	P
C_{58}	G	VG	G	G	VG
C_{59}	MP	MP	P	P	MP
$C_{5,10}$	M	M	M	M	M
$C_{5,11}$	G	G	G	G	MG
$C_{5,12}$	G	G	G	G	G
$C_{5,13}$	VG	G	VG	G	G
$C_{5,14}$	G	G	G	G	G
$C_{5,15}$	P	MP	MP	MP	MP
$C_{5,16}$	P	M	MG	MG	G
$C_{5,17}$	G	G	G	G	MG
$C_{5,18}$	G	G	G	G	G
$C_{5,19}$	VG	G	G	G	G
C_{61}	MP	MP	P	P	P
C_{62}	G	G	G	G	VG
C_{63}	MP	P	P	P	MP
C_{64}	M	M	M	M	M
C_{71}	G	G	G	G	MG
C_{72}	G	G	G	G	G
C_{73}	VG	G	G	G	G
C_{74}	G	G	G	G	G
C_{75}	P	MP	MP	P	P
C_{76}	G	MG	G	G	MG
C_{77}	G	G	G	G	G

Continued on next page

Table 4.4 – continued from previous page

2nd level indices	Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
C_{78}	VG	VG	VG	G	G
C_{79}	G	G	G	G	G
$C_{7,10}$	P	P	MP	MP	MP
$C_{7,11}$	P	M	MG	MG	G
$C_{7,12}$	G	G	G	G	MG
C_{81}	G	G	G	VG	G
C_{82}	VG	G	G	G	G
C_{83}	MP	MP	P	MP	MP
C_{84}	G	G	G	G	VG
C_{85}	MP	P	P	P	MP
C_{86}	M	M	M	MP	M
C_{87}	G	G	G	G	MG
C_{88}	G	G	G	G	G
C_{89}	VG	G	VG	G	G
$C_{8,10}$	G	G	G	G	G
$C_{8,11}$	P	P	MP	MP	MP
$C_{8,12}$	P	M	MG	MG	G
$C_{8,13}$	G	G	VG	G	MG
$C_{8,14}$	G	G	G	VG	G
$C_{8,15}$	VG	G	VG	G	G
$C_{8,16}$	MP	MP	P	MP	MP
$C_{8,17}$	G	G	G	G	VG
$C_{8,18}$	MP	P	P	P	MP
$C_{8,19}$	VG	VG	VG	VG	G
$C_{8,20}$	G	G	G	VG	G
$C_{8,21}$	P	P	MP	P	MP
$C_{8,22}$	P	M	MG	MG	G
$C_{8,23}$	G	G	G	G	G
$C_{8,24}$	G	G	G	G	G

Table 4.5: Priority Weight (in linguistic scale) of 2nd level indices assigned by DMs

2nd level indices	Priority Weight (in linguistic scale) of 2nd level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
C_{11}	H	H	H	H	VH
C_{12}	H	H	MH	H	H
C_{13}	H	H	H	H	H
C_{14}	VH	H	VH	H	H
C_{15}	H	H	H	VH	VH

Continued on next page

Table 4.5 – continued from previous page

2nd level indices	Priority Weight (in linguistic scale) of 2nd level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
C_{16}	H	H	H	VH	H
C_{17}	MH	H	H	H	H
C_{18}	VH	VH	H	H	VH
C_{19}	VH	H	H	H	VH
$C_{1,10}$	MH	H	H	H	H
$C_{1,11}$	H	H	H	H	H
C_{21}	VH	H	VH	H	H
C_{22}	H	VH	H	VH	VH
C_{23}	H	H	H	VH	H
C_{24}	MH	H	H	H	H
C_{25}	VH	VH	H	H	VH
C_{26}	VH	H	H	H	VH
C_{27}	MH	H	H	H	H
C_{31}	H	H	H	H	H
C_{32}	VH	H	H	H	H
C_{33}	H	VH	H	VH	VH
C_{34}	H	H	H	H	H
C_{35}	MH	H	H	H	H
C_{36}	VH	VH	H	H	VH
C_{37}	VH	H	H	H	VH
C_{38}	MH	H	H	H	H
C_{41}	H	H	H	H	H
C_{42}	VH	H	H	H	H
C_{43}	H	VH	H	VH	VH
C_{44}	H	H	H	VH	H
C_{45}	MH	H	H	H	H
C_{46}	VH	VH	H	H	H
C_{51}	VH	H	H	H	VH
C_{52}	MH	H	MH	H	H
C_{53}	H	H	H	H	H
C_{54}	VH	H	H	H	H
C_{55}	H	VH	H	VH	VH
C_{56}	H	H	H	VH	H
C_{57}	MH	H	H	H	H
C_{58}	VH	VH	H	H	VH
C_{59}	VH	H	H	H	VH
$C_{5,10}$	MH	H	H	H	H
$C_{5,11}$	H	H	H	H	H
$C_{5,12}$	VH	H	H	H	H
$C_{5,13}$	H	VH	H	VH	VH
$C_{5,14}$	H	H	H	VH	H
$C_{5,15}$	MH	H	H	H	H
$C_{5,16}$	VH	VH	H	H	VH

Continued on next page

Table 4.5 – continued from previous page

2nd level indices	Priority Weight (in linguistic scale) of 2^{nd} level indices assigned by DMs				
	DM1	**DM2**	**DM3**	**DM4**	**DM5**
$C_{5,17}$	VH	H	H	H	H
$C_{5,18}$	MH	H	MH	H	H
$C_{5,19}$	H	H	H	H	H
C_{61}	VH	H	VH	H	H
C_{62}	H	VH	H	VH	VH
C_{63}	H	H	H	VH	H
C_{64}	MH	H	H	H	H
C_{71}	VH	VH	H	H	VH
C_{72}	VH	H	H	H	VH
C_{73}	MH	H	H	H	H
C_{74}	H	H	H	H	H
C_{75}	VH	H	VH	H	H
C_{76}	H	VH	H	VH	VH
C_{77}	H	H	H	VH	H
C_{78}	MH	H	H	H	H
C_{79}	VH	VH	H	H	VH
$C_{7,10}$	VH	H	H	H	VH
$C_{7,11}$	MH	H	MH	H	H
$C_{7,12}$	H	H	H	H	H
C_{81}	VH	H	VH	H	H
C_{82}	H	VH	H	VH	VH
C_{83}	H	H	H	VH	H
C_{84}	MH	H	H	H	H
C_{85}	VH	VH	H	H	VH
C_{86}	VH	H	H	H	VH
C_{87}	MH	H	H	H	H
C_{88}	H	H	H	H	H
C_{89}	VH	H	H	H	H
$C_{8,10}$	H	VH	H	VH	VH
$C_{8,11}$	H	H	H	VH	H
$C_{8,12}$	H	H	H	H	H
$C_{8,13}$	H	VH	H	H	VH
$C_{8,14}$	VH	H	H	H	VH
$C_{8,15}$	MH	H	MH	H	H
$C_{8,16}$	H	H	H	H	H
$C_{8,17}$	VH	H	VH	H	H
$C_{8,18}$	H	VH	H	VH	H
$C_{8,19}$	H	H	H	H	H
$C_{8,20}$	MH	H	H	H	H
$C_{8,21}$	VH	VH	H	H	VH
$C_{8,22}$	VH	H	H	H	VH
$C_{8,23}$	MH	H	MH	H	H
$C_{8,24}$	H	H	H	H	H

Table 4.6: Priority Weight (in linguistic scale) of 1st level indices assigned by DMs

1st level indices	**Priority Weight (in linguistic scale) of 1st level indices assigned by DMs**				
	DM1	**DM2**	**DM3**	**DM4**	**DM5**
C_1	VH	H	H	H	VH
C_2	MH	H	MH	H	H
C_3	H	H	H	H	H
C_4	VH	H	VH	H	H
C_5	H	VH	H	VH	VH
C_6	H	H	H	VH	H
C_7	MH	H	H	H	H
C_8	VH	VH	H	H	VH

Table 4.7: Aggregated Fuzzy Priority Weight and Aggregated Fuzzy Rating of 2nd level indices

2nd level indices	**Aggregated Fuzzy Priority Weight, w_{ij}**	**Aggregated Fuzzy Rating, U_{ij}**
C_{11}	$(0.73, 0.83, 0.92)$	$(0.18, 0.32, 0.46)$
C_{12}	$(0.66, 0.77, 0.88)$	$(0.30, 0.50, 0.70)$
C_{13}	$(0.70, 0.80, 0.90)$	$0.54, 0.68, 0.82)$
C_{14}	$(0.76, 0.86, 0.94)$	$(0.66, 0.77, 0.88)$
C_{15}	$(0.76, 0.86, 0.94)$	$(0.40, 0.56, 0.72)$
C_{16}	$(0.73, 0.83, 0.92)$	$(0.66, 0.77, 0.88)$
C_{17}	$(0.66, 0.77, 0.88)$	$(0.70, 0.80, 0.90)$
C_{18}	$(0.79, 0.89, 0.96)$	$(0.76, 0.86, 0.94)$
C_{19}	$(0.76, 0.86, 0.94)$	$(0.70, 0.80, 0.90)$
$C_{1,10}$	$(0.66, 0.77, 0.88)$	$(0.16, 0.29, 0.42)$
$C_{1,11}$	$(0.70, 0.80, 0.90)$	$(0.30, 0.50, 0.70)$
C_{21}	$(0.76, 0.86, 0.94)$	$(0.58, 0.71, 0.84)$
C_{22}	$(0.79, 0.89, 0.96)$	$(0.70, 0.80, 0.90)$
C_{23}	$(0.73, 0.83, 0.92)$	$(0.44, 0.59, 0.74)$
C_{24}	$(0.66, 0.77, 0.88)$	$(0.66, 0.77, 0.88)$
C_{25}	$(0.79, 0.89, 0.96)$	$(0.70, 0.80, 0.90)$
C_{26}	$(0.76, 0.86, 0.94)$	$(0.76, 0.86, 0.94)$
C_{27}	$(0.66, 0.77, 0.88)$	$(0.16, 0.29, 0.42)$
C_{31}	$(0.70, 0.80, 0.90)$	$(0.76, 0.86, 0.94)$
C_{32}	$(0.73, 0.83, 0.92)$	$(0.16, 0.29, 0.42)$
C_{33}	$(0.79, 0.89, 0.96)$	$(0.30, 0.50, 0.70)$
C_{34}	$(0.70, 0.80, 0.90$	$(062, 0.74, 0.86)$
		Continued on next page

Table 4.7 – continued from previous page

2nd level indices	Aggregated Fuzzy Priority Weight, w_{ij}	Aggregated Fuzzy Rating, U_{ij}
C_{35}	$(0.66, 0.77, 0.88)$	$(0.70, 0.80, 0.90)$
C_{36}	$(0.79, 0.89, 0.96)$	$(0.48, 0.62, 0.76)$
C_{37}	$(0.76, 0.86, 0.94)$	$(0.66, 0.77, 0.88)$
C_{38}	$(0.66, 0.77, 0.88)$	$(0.70, 0.80, 0.90)$
C_{41}	$(0.70, 0.80, 0.90)$	$(0.76, 0.86, 0.94)$
C_{42}	$(0.73, 0.83, 0.92)$	$(0.14, 0.26, 0.38)$
C_{43}	$(0.79, 0.89, 0.96)$	$(0.73, 0.83, 0.92)$
C_{44}	$(0.73, 0.83, 0.92)$	$(0.70, 0.80, 0.90)$
C_{45}	$(0.66, 0.77, 0.88)$	$(0.14, 0.26, 0.38)$
C_{46}	$(0.76, 0.86, 0.94)$	$(0.30, 0.50, 0.70)$
C_{51}	$(0.76, 0.86, 0.94)$	$(0.58, 0.71, 0.84)$
C_{52}	$(062, 0.74, 0.86)$	$(0.70, 0.80, 0.90)$
C_{53}	$(0.70, 0.80, 0.90)$	$(0.44, 0.59, 0.74)$
C_{54}	$(0.73, 0.83, 0.92)$	$(0.66, 0.77, 0.88)$
C_{55}	$(0.79, 0.89, 0.96)$	$(0.70, 0.80, 0.90)$
C_{56}	$(0.73, 0.83, 0.92)$	$(0.73, 0.83, 0.92)$
C_{57}	$(0.66, 0.77, 0.88)$	$(0.14, 0.26, 0.38)$
C_{58}	$(0.79, 0.89, 0.96)$	$(0.76, 0.86, 0.94)$
C_{59}	$(0.76, 0.86, 0.94)$	$(0.16, 0.29, 0.42)$
$C_{5,10}$	$(0.66, 0.77, 0.88)$	$(0.30, 0.50, 0.70)$
$C_{5,11}$	$(0.70, 0.80, 0.90)$	$(0.66, 0.77, 0.88)$
$C_{5,12}$	$(0.73, 0.83, 0.92)$	$(0.70, 0.80, 0.90)$
$C_{5,13}$	$(0.79, 0.89, 0.96)$	$(0.76, 0.86, 0.94)$
$C_{5,14}$	$(0.73, 0.83, 0.92)$	$(0.70, 0.80, 0.90)$
$C_{5,15}$	$(0.66, 0.77, 0.88)$	$(0.18, 0.32, 0.46)$
$C_{5,16}$	$(0.79, 0.89, 0.96)$	$(0.42, 0.56, 0.70)$
$C_{5,17}$	$(0.73, 0.83, 0.92)$	$(0.66, 0.77, 0.88)$
$C_{5,18}$	$(062, 0.74, 0.86)$	$(0.70, 0.80, 0.90)$
$C_{5,19}$	$(0.70, 0.80, 0.90)$	$(0.73, 0.83, 0.92)$
C_{61}	$(0.76, 0.86, 0.94)$	$(0.14, 0.26, 0.38)$
C_{62}	$(0.79, 0.89, 0.96)$	$(0.73, 0.83, 0.92)$
C_{63}	$(0.73, 0.83, 0.92)$	$(0.14, 0.26, 0.38)$
C_{64}	$(0.66, 0.77, 0.88)$	$(0.30, 0.50, 0.70)$
C_{71}	$(0.79, 0.89, 0.96)$	$(0.66, 0.77, 0.88)$
C_{72}	$(0.76, 0.86, 0.94)$	$(0.70, 0.80, 0.90)$
C_{73}	$(0.66, 0.77, 0.88)$	$(0.73, 0.83, 0.92)$
C_{74}	$(0.70, 0.80, 0.90)$	$(0.70, 0.80, 0.90)$
C_{75}	$(0.76, 0.86, 0.94)$	$(0.14, 0.26, 0.38)$
C_{76}	$(0.79, 0.89, 0.96)$	$(0.62, 0.74, 0.86)$
C_{77}	$(0.73, 0.83, 0.92)$	$(0.70, 0.80, 0.90)$
C_{78}	$(0.66, 0.77, 0.88)$	$(0.79, 0.89, 0.96)$
C_{79}	$(0.79, 0.89, 0.96)$	$(0.70, 0.80, 0.90)$
$C_{7,10}$	$(0.76, 0.86, 0.94)$	$(0.16, 0.29, 0.42)$
$C_{7,11}$	$(062, 0.74, 0.86)$	$(0.42, 0.56, 0.70)$

Continued on next page

Table 4.7 – continued from previous page

2nd level indices	Aggregated Fuzzy Priority Weight, w_{ij}	Aggregated Fuzzy Rating, U_{ij}
$C_{7,12}$	$(0.70, 0.80, 0.90)$	$(0.66, 0.77, 0.88)$
C_{81}	$(0.76, 0.86, 0.94)$	$(0.73, 0.83, 0.92)$
C_{82}	$(0.79, 0.89, 0.96)$	$(0.73, 0.83, 0.92)$
C_{83}	$(0.73, 0.83, 0.92)$	$(0.18, 0.32, 0.46)$
C_{84}	$(0.66, 0.77, 0.88)$	$(0.73, 0.83, 0.92)$
C_{85}	$(0.79, 0.89, 0.96)$	$(0.14, 0.26, 0.38)$
C_{86}	$(0.76, 0.86, 0.94)$	$(0.28, 0.47, 0.66)$
C_{87}	$(0.66, 0.77, 0.88)$	$(0.66, 0.77, 0.88)$
C_{88}	$(0.70, 0.80, 0.90)$	$(0.70, 0.80, 0.90)$
C_{89}	$(0.73, 0.83, 0.92)$	$(0.76, 0.86, 0.94)$
$C_{8,10}$	$(0.79, 0.89, 0.96)$	$(0.70, 0.80, 0.90)$
$C_{8,11}$	$(0.73, 0.83, 0.92)$	$(0.16, 0.29, 0.42)$
$C_{8,12}$	$(0.70, 0.80, 0.90)$	$(0.42, 0.56, 0.70)$
$C_{8,13}$	$(0.76, 0.86, 0.94)$	$(0.65, 0.80, 0.90)$
$C_{8,14}$	$(0.76, 0.86, 0.94)$	$(0.73, 0.83, 0.92)$
$C_{8,15}$	$(062, 0.74, 0.86)$	$(0.76, 0.86, 0.94)$
$C_{8,16}$	$(0.70, 0.80, 0.90)$	$(0.18, 0.32, 0.46)$
$C_{8,17}$	$(0.76, 0.86, 0.94)$	$(0.73, 0.83, 0.92)$
$C_{8,18}$	$(0.76, 0.86, 0.94)$	$(0.14, 0.26, 0.38)$
$C_{8,19}$	$(0.70, 0.80, 0.90)$	$(0.82, 0.92, 0.98)$
$C_{8,20}$	$(0.66, 0.77, 0.88)$	$(0.73, 0.83, 0.92)$
$C_{8,21}$	$(0.79, 0.89, 0.96)$	$(0.14, 0.26, 0.38)$
$C_{8,22}$	$(0.76, 0.86, 0.94)$	$(0.42, 0.56, 0.70)$
$C_{8,23}$	$(062, 0.74, 0.86)$	$(0.70, 0.80, 0.90)$
$C_{8,24}$	$(0.70, 0.80, 0.90)$	$(0.70, 0.80, 0.90)$

The 2nd level encompasses different sub-criterions under each of the 1st level main criterion. Performance evaluation is to be started at the 2nd level and then extended to the 1st level; and finally the overall performance extent is to be computed. In order to tackle ambiguity and vagueness arising from subjective decision-making information; linguistic data has been converted into fuzzy numbers to provide a strong mathematic basis of the performance evaluation forum thus facilitating clear understanding of the performing supply chain scenario towards effective decision-making. The procedural steps of performance appraisement have been listed below.

1. Form a committee of decision-makers for evaluating and appraising supply chain performance.

2. Choose appropriate linguistic variable towards expressing subjective preference of the decision-makers' against importance weight as well as ratings of individual evaluation indices.

3. Representing decision-makers' linguistic judgements using appropriate fuzzy numbers set. Convert linguistic weights and ratings into appropriate fuzzy numbers for the analysis purpose.

4. Use of fuzzy operational rules towards estimating aggregated fuzzy weight as well as aggregated fuzzy rating (pulled opinion of the decision-makers) for each of the evaluation criterion.

5. Calculation of computed performance rating of 1st level attributes and finally SC overall performance index called Fuzzy Performance Index (FPI).

   Appropriateness rating for each of the 1st level index (rating of evaluation index) has been computed as follows:

$$U_i = \frac{\sum U_{ij} \otimes w_{ij}}{\sum w_{ij}} \tag{4.1}$$

$$U_i = \frac{\sum_{j=1}^{m} U_{ij} \otimes w_{ij}}{\sum_{j=1}^{m} w_{ij}}$$

   In this expression (Eq. 4.1)is denoted as the aggregated fuzzy appropriateness rating against evaluation index (at 2nd level) which is undermain criterion in the 1st level. is the aggregated fuzzy weight against attribute (at 2nd level) which is undermain criterion in 1st level. Alsois the total number of criterions which are under1st level attributes. The Fuzzy Performance Index (FPI) has been computed as:

$$U(PFI) = \frac{\sum U_i \otimes w_i}{\sum w_i} \tag{4.2}$$

$$U(PFI) = \frac{\sum_{i=1}^{m} U_i \otimes w_i}{\sum_{i=1}^{m} w_i}$$

   In this expression (Eq. 4.2)is denoted as the computed fuzzy appropriateness rating (obtained using Eq. 4.1) against evaluation index at 1st level. is the aggregated fuzzy priority weight againstevaluation index in 1st level.is the total number of SC attributes in 1st level.

6. Investigation for identifying ill-performing areas those seek for future improvement. Calculate Fuzzy Performance Importance Index (FPII) of the 2nd level evaluation indices for indentifying ill-performing areas of the SC. After evaluating FPI, simultaneously it is felt indeed necessary to identify and analyze weak (ill-performing) areas in which organizational SC may require future improvement. Fuzzy Performance Importance Index (FPII) may be used to identify these ill-performing areas. FPII combines the performance rating and importance weight of various 2nd level indices. The higher the FPII of a factor, the higher is the contribution. The concept of FPII was introduced by (Lin et al.[35], 2006) for agility extent measurement in supply chain.

7. Calculate performance ranking order (of individual 2nd level evaluation indices) based on crisp value. The concept of ranking method introduced by (Thorani et al.[34], 2012) has been adapted here to rank FPIIs of individual 2nd level evaluation indices.

Chapter 5

Empirical Research

The two-level criteria hierarchy for supply chain performance evaluation adopted in this study has been furnished in Table 4.1. Table 4.2-4.3 represents seven-member linguistic terms (and their corresponding generalized triangular fuzzy numbers) for analyzing decision-making information. In order to provide priority weight against various attributes (1st level) as well as criteria (2nd level); the decision-making group has been instructed to use the following linguistic terms: Very Low (VL), Low (L), Medium Low (ML), Medium (M), Medium High (H), High (H), and Very High (VH). The following linguistic scale has been utilized to assign performance appropriateness rating against 2nd level criterions: Very Poor (VP), Poor (P), Medium Poor (MP), Medium (M), Medium Good (MG), Good (G) and Very Good (VG). Assuming a decision-making group consists of five decision-makers (DMs): DM1, DM2, DM3, DM4, and DM5. Assume that appropriateness rating (in linguistic scale) of 2nd level criterions assigned by DMs given in Table 4.4. Priority weights (in linguistic scale) of 2nd level indices and 1st level indices assigned by DMs have been given in Tables 4.5-4.6 respectively. Linguistic decision-making information has been transformed into triangular fuzzy numbers. Aggregated fuzzy appropriateness rating and aggregated fuzzy priority weight of 2nd level criterions have been computed and shown in Table 4.7.

Overall SC performance extent (Fuzzy Performance Index) thus becomes: (0.32, 0.66, 1.20) After evaluating FPI, the next step is to rank different 2nd level indices in accordance with their FPII. Thus, ill-performing areas can easily be sorted out and future improvement opportunities can be identified. Computed values of FPII (with corresponding crisp score) against individual 2nd level criterions have been shown in Table 5.1. Ranking order (based on crisp score) facilitates in realizing ill-performing areas of the said supply chain.

Table 5.1: Ranking order of 2nd level indices

2nd level indices	FPII	Crisp Value	Ranking Order
C11	(0.049, 0.054, 0.037)	0.017	78
C12	(0.102, 0.115, 0.115)	0.036	43
C13	(0.162, 0.136, 0.082)	0.044	31
C14	(0.158, 0.108, 0.053)	0.036	44
C15	(0.096, 0.078, 0.043)	0.025	66
C16	(0.178, 0.131, 0.070)	0.043	32
C17	(0.238, 0.184, 0.108)	0.06	9
C18	(0.160, 0.095, 0.038)	0.032	51
C19	(0.168, 0.112, 0.054)	0.037	40
C1,10	(0.054, 0.067, 0.050)	0.021	71
C1,11	(0.090, 0.100, 0.070)	0.031	55
C21	(0.139, 0.099, 0.050)	0.033	49
C22	(0.147, 0.088, 0.036)	0.03	59
C23	(0.119, 0.100, 0.059)	0.032	52
C24	(0.224, 0.177, 0.106)	0.058	12
C25	(0.147, 0.088, 0.036)	0.03	60
C26	(0.182, 0.120, 0.056)	0.04	35
C27	(0.054, 0.067, 0.050)	0.021	72
C31	(0.228, 0.172, 0.094)	0.056	14
C32	(0.043, 0.049, 0.034)	0.015	81
C33	(0.063, 0.055, 0.028)	0.017	79
C34	(0.186, 0.148, 0.086)	0.048	23
C35	(0.238, 0.184, 0.108)	0.06	10
C36	(0.101, 0.068, 0.030)	0.022	69
C37	(0.158, 0.108, 0.053)	0.036	45

Chapter 6

Conclusion

In recent years, supply chain management has been viewed a major component of competitive strategy to enhance organizational productivity and profitability. Supply chain management creates value for companies, customers and stakeholders interacting throughout a supply chain. The strategic dimension of supply chains makes it paramount that their performances are measured (Estampe et al.[36], 2010). The proposed methodology of using fuzzy logic in monitoring performance of a supply chain network has been highlighted in this paper. An efficient fuzzy based Decision-Support System (DSS) for supply chain performance measurement has been reported in this paper. By using the above methodology, the managers can easily indentify ill-performing areas which need future attention to enhance supply chain performance extent.

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