Green Supply Chain Performance Assessment: Exploration Fuzzy Logic to Tackle Linguistic Evaluation Information

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By

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Certificate of Approval

This is to certify that the thesis entitled **Green Supply Chain Performance Assessment: Exploration Fuzzy Logic to Tackle Linguistic Evaluation Information** submitted by ***Sri Amit Prem Prakash Minj*** has been carried out under my supervision in partial fulfillment of the requirements for the Degree of ***Bachelor of Technology*** in ***Mechanical Engineering*** at **National Institute of Technology**, **NIT Rourkela**, and this work has not been submitted elsewhere before for any other academic degree/diploma.

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Abstract

Green Supply Chain Management (GSCM) has appeared as an environmental innovation integrating environmental concerns into the supply chain management. Due to recent modification in environmental requirements, Govt. rules and regulations that affect manufacturing operations and services; growing attention is being given towards inclusion of environmental management strategies into traditional concept of supply chains. A Green Supply Chain (GSC) aims at confining the wastes within the industrial system so as to conserve energy and prevent the dissipation of harmful materials into the environment. In order to assess GSC performance extent, 'green attributes' must be considered along with traditional SC performance indices. The present work aims to discuss a methodology to deal with linguistic evaluation information through fuzzy logic for evaluating green supply chain performance and also attempts in identifying and prioritizing the key factors towards increasing 'green competitiveness'. Here, the performance criteria/attributes have been evaluated by the expert group through linguistic variables which have further been transformed into Generalized Trapezoidal Fuzzy Numbers (GTFNs). Linguistic assessment of GSCM has been carried out based on different attributes, such as customer value, quality evaluation, performance measurement, appropriate price and environmental effect. Each attribute is followed by several criterions. Because of the vague and inconsistent nature of decision-makers' linguistic evaluation information associated with GSCM; a fuzzy-based approach is indeed required to convert linguistic data into appropriate fuzzy numbers, for the analysis purpose. Apart from computing overall green performance extent, this research has been extended to identify ill-performing areas of an organizational GSC. Moreover, a case study has been reported in support of application feasibility of the proposed module.

Keywords: Green Supply Chain Management (GSCM), Generalized Trapezoidal Fuzzy Numbers (GTFN)

Contents

1. Introduction and Literature Review

Confronted with the diminishing raw materials, overflowing waste lands, alarming increase in environmental deterioration along with enormous rise in level of pollution, enterprises have now been forced to incorporate environmental issues in today's business practices. It is essential not only to make the business environmentally benign, but also, for better business sense and profits to survive in the present competitive world. It is the economic globalization and pressure from the consumer community, laws and environmental standards that are acting as the motive force behind the enterprises to improve their environmental performance as well.

The Supply Chain Management (SCM) being a series of activities associated with manufacturing, starting from raw material acquisition to finished product delivery; also have significant environmental impacts at each level of operations. Therefore, an environmentally conscious SCM, termed as Green Supply Chain Management (GSCM), fetching popularity in practice as eco-friendly consumption and production has been an essential part of the strategy to improve environmental quality and economic growth leading towards improvements in health, working conditions, and sustainability. GSCM involves traditional supply chain management practices, which integrate environmental criteria, or concerns, into organizational purchasing decision and long term relationships with suppliers (Gilbert, 2000).

As the GSCM finds its root in the traditional SCM, obviously it could be considered similar to the SCM activities after adding a green parameter to the individual operations which is meant to assess the influence and relationships of SCM to the environment. A typical GSCM thus idealized as follows:

Green Sourcing and Procurement

Green Manufacturing

Green Warehousing

Green Distribution

Green Packaging

Green Logistics

Pioneer researchers (Lambert and Cooper, 2000; Srivastava, 2007; Ninlawan et al. 2010; Pishvaee et al., 2012; Wang, 2012; Wang et al., 2011; Muralidhar et al., 2012) have been trying to establish green performance index to find appropriate measurements for environmental impacts. Beamon (1999) investigated the environmental factors leading to the development of an extended environmental supply chain. It described the elemental differences between the extended supply chain and the traditional supply chain. Zhua and Sarkis (2004) examined the relationships between GSCM practice and environmental as well as economic performance. Using moderated hierarchical regression analysis, the authors evaluated the general relationships between specific GSCM practices and performance; then investigated how two primary types of management operations philosophies, quality management and just-in-time (or lean) manufacturing principles, influenced the relationship between GSCM practices and performance. Hervani et al. (2005) seek to integrate supply chain management, environmental management, and performance management into one framework. Zhu et al. (2008) aimed to empirically investigate the construct of and the scale for evaluating green supply chain management (GSCM) practices implementation among manufacturers. With data collected from numerous Chinese manufacturers, two measurement models of GSCM practices implementation were tested and compared by confirmatory factor analysis. The empirical findings suggested that both the first-order and the second-order models for GSCM implementation were found reliable and valid.

Performance assessment of GSC can be viewed as a Multi-Attribute Group Decision Making (MAGDM) process involving numerous evaluation criteria/attributes. Subjectivity of evaluation indices (criteria/attributes) invites incompleteness, imprecision and inconsistency in the decision-making. Because, human judgment (evaluation information collected from the expert group of decision-makers) are often vague in nature. Fuzzy logic has the capability in dealing with such type of fuzziness in the information and facilitates the said decision-modeling.

To this end, present work aims to establish an efficient fuzzy based appraisement platform towards performance evaluation of GSC.

2. Fuzzy Preliminaries

Fuzzy logic is basically a multi-value logic which permits intermediate values to be defined between conventional ones like true/false, low/high, good/bad, etc. It is an established fact that, as the complexities surrounding a system increase, making a precise statement about the state of the system becomes very difficult.

To deal with vagueness in human thought, Zadeh (1965) 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 (1975), Buckley (1985), Negi (1989), Kaufmann and Gupta (1991).The basic definitions and notations below will be used throughout this paper until otherwise stated.

2.1 Definitions of fuzzy sets:

Definition 1. A fuzzy set $\tilde{A}$ in a universe of discourse X is characterized 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, 1991).

Definition 2. A fuzzy set $\tilde{A}$ in a universe of discourse X is convex if and only if

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

(1)

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

Definition 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, 1995).

2.2 Definitions of fuzzy numbers:

Definition 1. A fuzzy number is a fuzzy subset in the universe of discourse X that is both convex and normal. Fig. 1 shows a fuzzy number $\tilde{n}$ in the universe of discourse X that conforms to this definition (Kaufmann and Gupta, 1991).

Definition 2. The α-cut of fuzzy number $\tilde{n}$ is defined as:

$$\tilde{n}^{\alpha} = \{x_i : \mu_{\tilde{n}}(x_i) \geq \alpha, x_i \in X\}, \tag{2}$$

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, 1991; Zimmermann, 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, 1989).

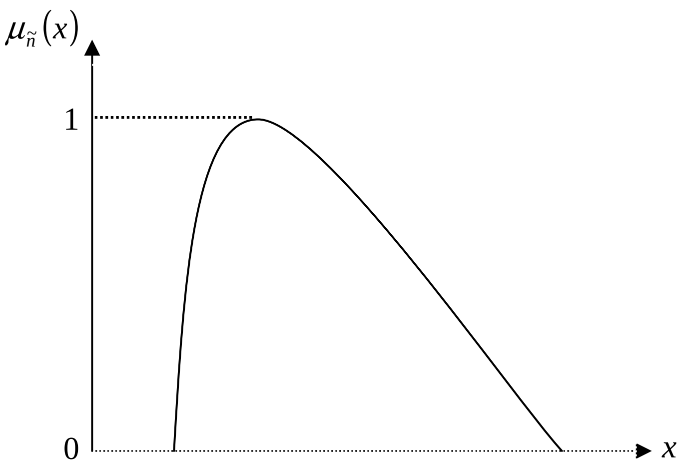

Fig. 1. A fuzzy number $\tilde{n}$

Definition 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:

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-a)/(b-a), & if\ a \leq x \leq b, \\ (c-x)/(c-b), & if\ b \leq x \leq c, \\ 0, & otherwise, \end{cases} \quad (3)$$

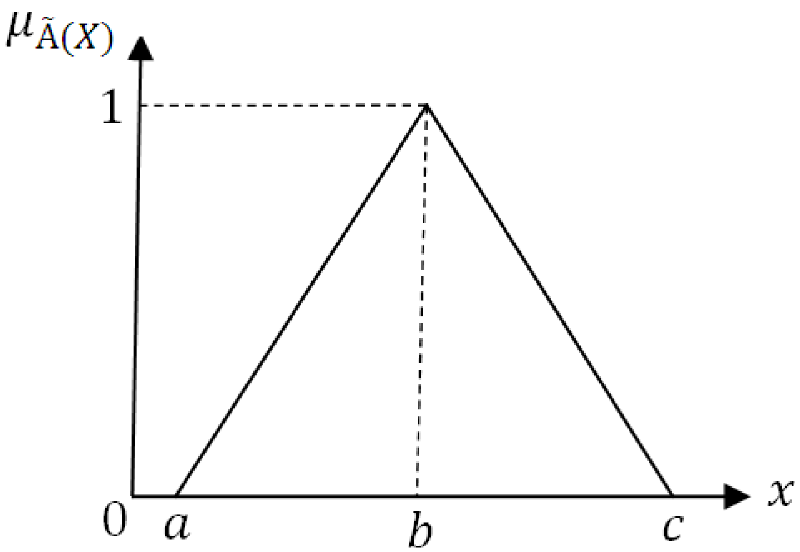

Fig. 2. A triangular fuzzy number $\tilde{A}$

Based on extension principle, the fuzzy sum $\oplus$ and fuzzy subtraction Θ 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, 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:

$$\tilde{A}_1 \oplus \tilde{A}_2 = (a_1 + a_2, b_1 + b_2, c_1 + c_2) \quad (4)$$

$$\tilde{A}_1 \Theta \tilde{A}_2 = (a_1 - a_2, b_1 - b_2, c_1 - c_2), \text{(5)}\ \tilde{A}_1 \otimes \tilde{A}_2 = (a_1 a_2, b_1 b_2, c_1 c_2), \quad (6)$$

$$r \otimes \tilde{A}_1 = (ra_1, rb_1, rc_1), \quad (7)$$

$$\tilde{A}_1 \varnothing \tilde{A}_2 = (a_1/c_2, b_1/b_2, c_1/a_2), \quad (8)$$

The operations of $\vee$ (max) and $\wedge$ (min) are defined as:

$$\tilde{A}_1 (\vee) \tilde{A}_2 = (a_1 \vee a_2, b_1 \vee b_2, c_1 \vee c_2), \quad (9)$$

$$\tilde{A}_1 (\wedge) \tilde{A}_2 = (a_1 \wedge a_2, b_1 \wedge b_2, c_1 \wedge c_2), \quad (10)$$

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, 2010)

$$\text{BNP}_i = \frac{[(c-a)+(b-a)]}{3} + a, \qquad \forall_i, \quad (11)$$

Definition 4. A matrix $\tilde{\mathbf{D}}$ is called a fuzzy matrix if at least one element is a fuzzy number (Buckley, 1985)

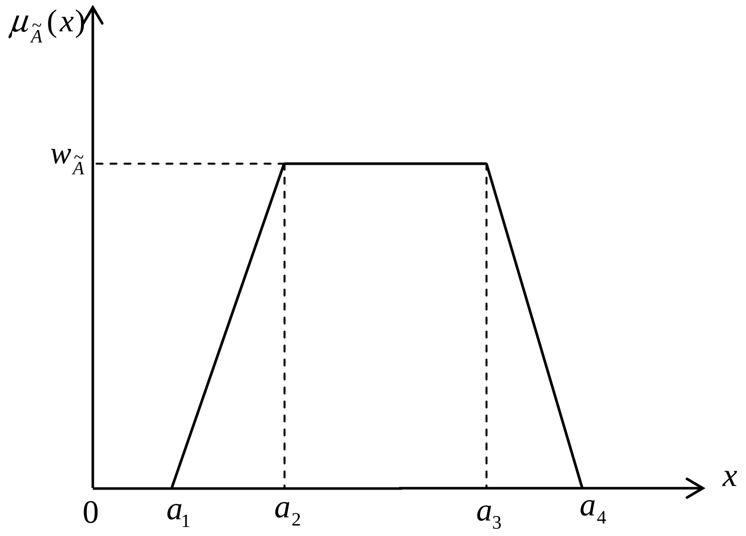

Fig. 3 Trapezoidal fuzzy number $\tilde{A}$

2.3 Linguistic variable:

Definition 1. A linguistic variable is the variable whose values are not expressed in numbers but words or sentences in a natural or artificial language (Zadeh, 1975). The concept of a linguistic variable is very useful in dealing with situations, which are too complex or not well-defined to be reasonably described in conventional quantitative expressions (Zimmermann, 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.

2.4 The concept of generalized trapezoidal fuzzy numbers

By the definition given by (Chen, 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.

and the membership function $\mu_{\tilde{A}}(x): R \to [0,1]$ is defined as follows:

$$\mu_{\tilde{A}}(x)=\begin{cases}\frac{x-a_1}{a_2-a_1}\times w_{\tilde{A}}, & x\in(a_1,a_2)\\ w_{\tilde{A}}, & x\in(a_2,a_3)\\ \frac{x-a_4}{a_3-a_4}\times w_{\tilde{A}}, & x\in(a_3,a_4)\\ 0, & x\in(-\infty,a_1)\cup(a_4,\infty)\end{cases} \tag{12}$$

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

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 $-1 \le a_1 \le a_2 \le a_3 \le a_4 \le 1$, 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, 2009):

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

$$(a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4; \min(w_{\tilde{a}}, w_{\tilde{b}})) \tag{13}$$

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

$$(a_1 - b_4, a_2 - b_3, a_3 - b_2, a_4 - b_1; \min(w_{\tilde{a}}, w_{\tilde{b}})) \tag{14}$$

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

$$\left(a, b, c, d; \min\left(w_{\tilde{a}}, w_{\tilde{b}}\right)\right) \quad (15)$$

Here,

$$a = \min\left(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4\right)$$

$$b = \min\left(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3\right)$$

$$c = \max\left(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3\right)$$

$$d = \max\left(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4\right)$$

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

$$\tilde{a} \otimes \tilde{b} = \left(a1 \times b1, a2 \times b2, a3 \times b3, a4 \times b4; \min\left(w_{\tilde{a}}, w_{\tilde{b}}\right)\right)$$

$$\tilde{a} / \tilde{b} = \left(a_1, a_2, a_3, a_4; w_{\tilde{a}}\right) \Big/ \left(b_1, b_2, b_3, b_4; w_{\tilde{b}}\right)$$

$$= \left(a_1 / b_4, a_2 / b_3, a_3 / b_2, a_4 / b_1; \min\left(w_{\tilde{a}}, w_{\tilde{b}}\right)\right) \quad (16)$$

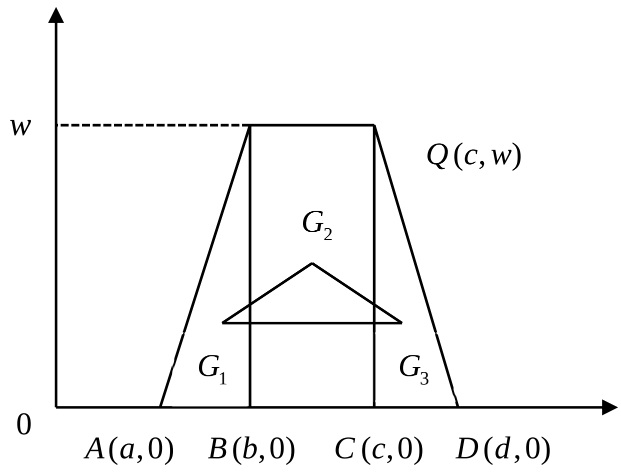

Fig. 4. Trapezoidal Fuzzy Number [Thorani et al. (2012)]

Chen and Chen (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:

$$y_{\tilde{a}} = \begin{cases} \dfrac{w_{\tilde{a}} \times \left(\dfrac{a_3 - a_2}{a_4 - a_1} + 2 \right)}{6}, & if\ a_1 \neq a_4 \\ \dfrac{w_{\tilde{a}}}{2}, & if\ a_1 = a_4 \end{cases} \quad (17)$$

$$x_{\tilde{a}} = \frac{y_{\tilde{a}} \times (a_2 + a_3) + (a_1 + a_4) \times (w_{\tilde{a}} - y_{\tilde{a}})}{2 \times w_{\tilde{a}}} \quad (18)$$

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

The centroid of a trapezoid is considered as the balancing point of the trapezoid (Fig. 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 G_1, G_2, and G_3 respectively. The Incenter of these Centroids G_1, G_2 and G_3 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. 4). The Centroids of the three plane figures are $G_1 = \left(\frac{a+2b}{3}, \frac{w}{3} \right)$, $G_2 = \left(\frac{b+c}{2}, \frac{w}{2} \right)$ and $G_3 = \left(\frac{2c+d}{3}, \frac{w}{3} \right)$ respectively.

Equation of the line $\overline{G_1G_3}$ is $y = \frac{w}{3}$ and G_2 does not lie on the line $\overline{G_1G_3}$. Therefore, G_1G_2 and G_3 are non-collinear and they form a triangle.

We define the Incentre $I_{\tilde{A}}(\bar{x}_0, \bar{y}_0)$ 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

$$I_{\tilde{A}}(\bar{x}_0, \bar{y}_0) = \left(\frac{\alpha\left(\frac{a+2b}{3}\right) + \beta\left(\frac{b+c}{2}\right) + \gamma\left(\frac{2c+d}{3}\right)}{\alpha+\beta+\gamma}, \frac{\alpha\left(\frac{w}{3}\right) + \beta\left(\frac{w}{2}\right) + \gamma\left(\frac{w}{3}\right)}{\alpha+\beta+\gamma} \right) \tag{19}$$

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. $c = b$ the in-center of Centroids is given by

$$I_{\tilde{A}}(\bar{x}_0, \bar{y}_0) = \left(\frac{x\left(\frac{a+2b}{3}\right) + yb + z\left(\frac{2b+d}{3}\right)}{x+y+z}, \frac{x\left(\frac{w}{3}\right) + y\left(\frac{w}{2}\right) + z\left(\frac{w}{3}\right)}{x+y+z} \right) \tag{20}$$

Here,

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

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

The ranking function of the generalized trapezoidal fuzzy number $\tilde{A} = (a,b,c,d;w)$, which maps the set of all fuzzy numbers to a set of real numbers is defined as,

$$R(\tilde{A}) = x_0 \times y_0 = \left(\frac{x\left(\frac{a+2b}{3}\right) + yb + z\left(\frac{2b+d}{3}\right)}{x+y+z} \times \frac{x\left(\frac{w}{3}\right) + y\left(\frac{w}{2}\right) + z\left(\frac{w}{3}\right)}{x+y+z} \right) \tag{21}$$

This is the Area between the incenter of the centroids $I_{\tilde{A}}(\bar{x}_0, \bar{y}_0)$ as defined in Eq. (19) and the original point.

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

$$m = \frac{1}{2}\int_0^w (b+c)dx = \frac{w}{2}(b+c) \tag{22}$$

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

$$s = \int_0^w (d-a)dx = w(d-a) \tag{23}$$

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

$$ls = \int_0^w (b-a)dx = w(b-a) \tag{24}$$

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

$$rs = \int_0^w (d - c) dx = w(d - c) \tag{25}$$

Using the above definitions we now define the ranking procedure of two generalized trapezoidal fuzzy numbers.

Let $\tilde{A} = (a_1, b_1, c_1, d_1; w_1)$ and $\tilde{B} = (a_2, b_2, c_2, d_2; w_2)$ 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_1 and w_2

Case (i) If $w_1 > w_2$ then $\tilde{A} > \tilde{B}$

Case (ii) If $w_1 < w_2$ then $\tilde{A} < \tilde{B}$

Case (iii) If $w_1 = w_2$ then $\tilde{A} \approx \tilde{B}$

3. Proposed Performance Appraisement Module

A fuzzy based Green Supply Chain (GSC) performance appraisement module discussed in this paper has been presented below. It utilizes the concept of Generalized Trapezoidal Fuzzy Numbers (GTFNs) set. Consider a three-level criteria hierarchy (Table 1) of GSC performance indices.

Step 1: Formation of a committee of decision makers (DMs) for evaluating and appraising of GSC performance.

Step 2: Select the appropriate linguistic variables for assignment of importance weights (priority or preference) against each of the evaluation indices (at 1st, 2nd and 3rd level) as well as appropriateness rating for individual 3rd level evaluation indices.

Step 3: Convert linguistic information into fuzzy numbers by using the concept of generalized positive trapezoidal fuzzy numbers. Calculate aggregated fuzzy priority weight of evaluation indices (at 1st, 2nd and 3rd level) and aggregated fuzzy rating of 3rd level indices by help of fuzzy arithmetic operational rules.

Step 4: Calculate aggregated fuzzy rating of 2nd level followed by 1st level indices. Thus, aggregated fuzzy performance rating for 2nd level evaluation indices can be computed as: (Assume that there are m number of 1st level indices. Each 1st level index consists of n 2nd level index; and each 2nd level index comprises l number of 3rd level indices.

$$U_{ij} = \frac{\sum_{k=1}^{l}\left(w_{ijk} \otimes U_{ijk}\right)}{\sum_{k=1}^{l} w_{ijk}} \tag{26}$$

Here U_{ijk} represents aggregated performance rating and w_{ijk} is the aggregated fuzzy weight to 3rd level index C_{ijk}. Also U_{ij} is the computed fuzzy rating of j_{th} 2nd level index which is under i_{th} 1st level index.

Step 5: Calculate aggregated fuzzy rating of 1st level evaluation indices. Thus, aggregated fuzzy performance rating for 1st level evaluation indices can be computed as:

$$U_{i} = \frac{\sum_{k=1}^{n}\left(w_{ij} \otimes U_{ij}\right)}{\sum_{k=1}^{n} w_{ij}} \tag{27}$$

Here U_{ij} represents computed fuzzy performance rating (Eq. 26) and w_{ij} represents aggregated fuzzy weight corresponding to 2nd level index C_{ij}. Also U_i is the computed fuzzy rating of i_{th} 1st level index.

Step 6: Calculate overall fuzzy performance index U (FPI) can be obtained as in (Eq. 28).

$$U(FPI) = \frac{\sum_{k=1}^{m}(w_i \otimes U_i)}{\sum_{k=1}^{m} w_i} \tag{28}$$

Here U_i represents computed fuzzy performance rating (Eq. 27) and w_i represents aggregated fuzzy weight corresponding to 1st level index C_i.

FPI can be compared with predefined performance estimate fuzzy scale set by the management to check the existing performance level for the said green supply chain and to seek for week performing areas which need future improvement.

Step 7: After evaluating FPI, it is necessary to identify and analyze the week areas in the SC. Calculate Fuzzy Performance Importance Index (FPII) against individual 3rd level evaluation indices. FPII may be used to identify these ill-performing areas. The higher the FPII of a factor, the higher is the contribution (Lin et al., 2006). The FPII can be calculated as shown in (Eq. 29).

$$FPII_{ijk} = w_{ijk}^{'} \otimes U_{ijk} \tag{29}$$

Here, $w_{ijk}^{'} = [(1,1,1,1) - w_{ijk}]$ (30)

FPII need to be ranked to identify individual 3rd level attribute’s performance level. Based on that 3rd level indices can be ranked accordingly and ill-performing attributes can be sorted out. In future, the particular industry should pay attention towards improving those attribute aspects in order to boost up overall green supply chain performance extent. Ranking provides necessary information about comparative performance picture of existing green attributes.

4. Numerical Illustrations

In this paper the hierarchical model (Table. 1) consists of three level indices. Customer Value, Supply Chain Value and Environmental Value have been considered as the 1st level indices followed by 2nd level as well as 3rd level indices. A fuzzy based appraisement module has been used to evaluate an overall performance index. The proposed evaluation index platform has been explored by the supply chain of a famous automobile part manufacturing unit at eastern part of India.

The fuzzification of the expert judgments has been performed by using the trapezoidal fuzzy numbers; as used the linguistic variables for expressing importance weight (VL: 'Very Low'; L: 'Low'; ML: 'Moderate Low'; M: 'Moderate'; MH: 'Moderate High'; H: 'High'; VH: 'Very High') and appropriateness ratings (VP: 'Very Poor'; P: 'Poor'; MP: 'Moderate Poor'; F: 'Fair'; MF: 'Moderate Fair'; G: 'Good'; VG: 'Very Good') against each criterion. These variables corresponding to weight and rating expressed in 'seven-member linguistic' term set and their corresponding fuzzy numbers as shown in Table 2.

Table 3 and 4 shows appropriateness rating and priority weight (in linguistic scale), respectively, of 3rd level indices assigned by the Decision Makers (DMs). Table 5 and 6 shows linguistic priority weight of 2nd level and 1st level indices assigned by DMs.

Table 7 exhibits aggregated fuzzy weight as well as aggregated fuzzy rating against individual 3rd level evaluation indices. Aggregated fuzzy priority weight and computed fuzzy performance rating (Eq. 26) of 2nd level indices have been shown in Table 8. Table 9 exhibits aggregated fuzzy priority weight and computed fuzzy rating (Eq. 27) of 1st level indices.

The FPI of the said GSC has been computed (Eq. 28) as: **(0.21, 0.53, 0.77, 1.94)**.

Performance ranking order of individual 3rd level evaluation indices (based on FPII (Eq. 29) and crisp score) has been furnished in Table 11. This concept of ranking method based on crisp score, introduced by (Thorani et al., 2012) for a trapezoidal/triangular fuzzy number has been adapted in this research.

5. Conclusion

In the aforesaid research, the concept of fuzzy logic has been proposed to tackle linguistic evaluation information, corresponding to the hierarchical model of GSC performance appraisement, under uncertain environment, due to vagueness, inconsistency and incompleteness associated with decision-makers' subjective evaluation information. Apart from estimating overall performance index; the proposed module provides way to find out ill-performing areas in GSC which require special managerial attention for future improvement.

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Table 1: Green Supply Chain Performance Appraisement Platform

Goal	1st Level Indices	2nd Level Indices	3rd Level Indices
GSC Performance Evaluation Index, C	Customer Value, C_1	Flexibility, C_{11}	Product Flexibility, C_{111}
			Time Flexibility, C_{112}
			Quantity Flexibility, C_{113}
		Reliability, C_{12}	Out Rate, C_{121}
			On-Time Delivery Rate, C_{122}
			Customer Satisfaction, C_{123}
		Quality, C_{13}	Goods Return Rate, C_{131}
			The Time To Resolve Customer Complaints, C_{132}
		Price, C_{14}	Year Price Advantage, C_{141}
			The Average Frequency of a Single Product Promotions, C_{142}
	Supply Chain Value, C_2	Output, C_{21}	Supply Chain Profit, C_{211}
			Economic-Value Added, C_{212}
			Average Delay in Delivery Rate, C_{213}
			Average Rate of Early Delivery, C_{214}
			Average Waiting Rate, C_{215}
		Financial Situation, C_{22}	Operational Status of Assets, C_{221}
			Financial Earnings, C_{222}
			Development Capacity, C_{223}
			Return on Equity, C_{224}
			Ratio of Capital Maintenance and Appreciation, C_{225}
	Environmental Value, C_3	Degree of Environmental Impact, C_{31}	Waste Emission Targets, C_{311}
			Waste Ratio, C_{312}
			Waste Disposal, C_{313}
			Eco-Efficiency, C_{314}
			Recognition Degree of the Green Product, C_{315}
		Degree of Resource Consumption, C_{32}	Degree of Energy Consumption, C_{321}
			Degree of Material Consumption, C_{322}
			Degree of Energy Conservation, C_{323}
		Resource Recovery Rate, C_{33}	Recycled Material Utilization Ratio, C_{331}
			Product Recovery Rate, C_{332}
			Containers Recovery Rate, C_{333}

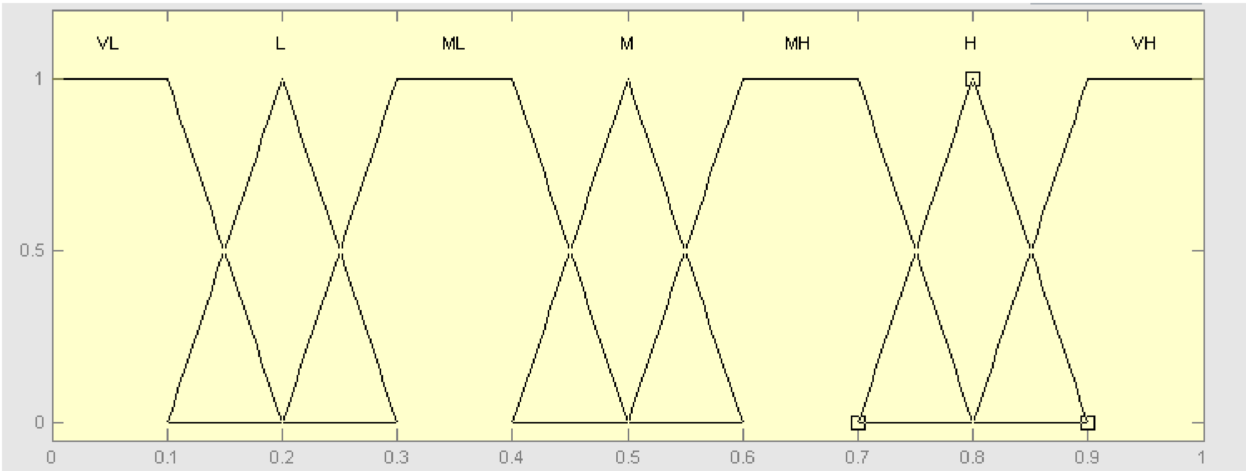

Fig. 1. Linguistic variables for importance weight of each criterion

VL: ‘Very Low’; L: ‘Low’; ML: ‘Moderate Low’; M: ‘Moderate’; MH: ‘Moderate High’; H: ‘High’; VH: ‘Very High’

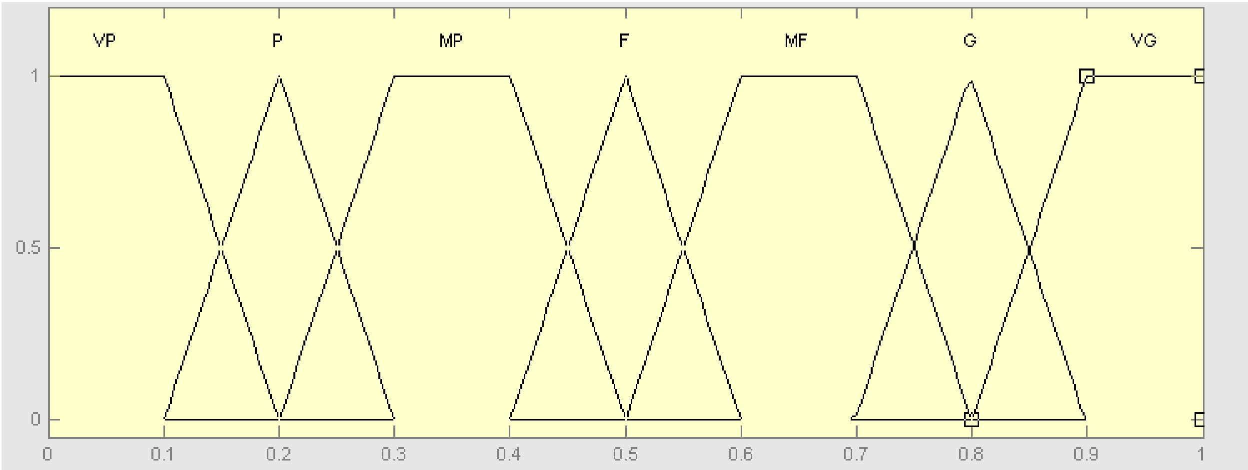

Fig. 2. Linguistic variables for ratings

VP: ‘Very Poor’; P: ‘Poor’; MP: ‘Moderate Poor’; F: ‘Fair’; MF: ‘Moderate Fair’; G: ‘Good’; VG: ‘Very Good’

Table 2: Seven-member linguistic terms and their corresponding fuzzy numbers

Linguistic terms for weight assignment	Linguistic terms for ratings	fuzzy numbers
Very Low, VL	Very poor, VP	(0.0, 0.0, 0.1, 0.2)
Low, L	Poor, P	(0.1, 0.2, 0.2, 0.3)
Moderate Low, ML	Moderate Poor, MP	(0.2, 0.3, 0.4, 0.5)
Moderate, M	Fair, F	(0.4, 0.5, 0.5, 0.6)
Moderate High, MH	Moderate Fair, MF	(0.5, 0.6, 0.7, 0.8)
High, H	Good, G	(0.7, 0.8, 0.8, 0.9)
Very High, VH	Very Good, VG	(0.8, 0.9, 1.0, 1.0)

Table 3: Appropriateness rating (in linguistic scale) of 3rd level indices assigned by DMs

3rd level indices	Appropriateness rating (in linguistic scale) of 3rd level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
C_{111}	G	G	VG	G	G
C_{112}	F	MF	G	G	G
C_{113}	F	F	MF	F	F
C_{121}	G	MF	MF	G	G
C_{122}	G	G	G	MF	G
C_{123}	F	F	MF	F	F
C_{131}	MP	MP	F	MP	MP
C_{132}	F	MF	F	MF	MF
C_{141}	MF	G	G	G	G
C_{142}	G	G	G	G	G
C_{211}	F	MF	F	MF	MF
C_{212}	G	G	G	VG	G
C_{213}	G	VG	G	MF	G
C_{214}	MP	F	MP	F	F
C_{215}	G	MF	MF	G	G
C_{221}	G	G	G	F	G
C_{222}	F	F	MF	F	F
C_{223}	MP	MP	F	MP	MP
C_{224}	F	MF	F	MF	MF
C_{225}	MF	G	G	G	G
C_{311}	G	G	MF	G	G
C_{312}	F	F	F	MF	MF
C_{313}	G	G	G	VG	G
C_{314}	G	VG	G	MF	G
C_{315}	MP	F	MP	F	F
C_{321}	G	MF	MF	G	G
C_{322}	G	G	G	MF	G
C_{323}	F	F	F	F	F
C_{331}	MP	MP	F	MP	MP
C_{332}	F	MF	F	MF	MF
C_{333}	MF	G	MF	G	G

Table 4: Priority Weight (in linguistic scale) of 3rd level indices assigned by DMs

3rd level indices	Priority Weight (in linguistic scale) of 2nd level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
C_{111}	H	H	H	VH	H
C_{112}	H	H	H	VH	VH
C_{113}	VH	H	MH	H	H
C_{121}	M	M	MH	H	H
C_{122}	H	H	VH	H	H
C_{123}	H	VH	VH	H	H
C_{131}	M	MH	MH	MH	MH
C_{132}	H	M	MH	H	H
C_{141}	H	H	H	VH	H
C_{142}	H	H	H	VH	VH
C_{211}	VH	H	MH	H	H
C_{212}	M	M	MH	H	H
C_{213}	H	H	VH	H	H
C_{214}	H	H	VH	H	H
C_{215}	M	H	MH	MH	MH
C_{221}	H	M	MH	H	H
C_{222}	H	H	H	VH	H
C_{223}	H	H	H	VH	VH
C_{224}	VH	H	H	H	H
C_{225}	M	M	MH	H	H
C_{311}	H	VH	H	H	H
C_{312}	H	VH	VH	H	H
C_{313}	M	MH	MH	MH	MH
C_{314}	H	M	MH	H	H
C_{315}	H	H	H	VH	H
C_{321}	H	VH	H	VH	VH
C_{322}	VH	H	H	H	H
C_{323}	M	MH	MH	H	H
C_{331}	H	H	H	H	H
C_{332}	H	VH	VH	H	H
C_{333}	M	MH	MH	MH	MH

Table 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	VH	VH	H
C_{12}	H	VH	H	VH	VH
C_{13}	VH	H	H	H	H
C_{14}	M	MH	H	H	H
C_{21}	H	H	H	H	H
C_{22}	H	VH	VH	H	H
C_{31}	M	MH	H	MH	MH
C_{32}	H	H	VH	VH	H
C_{33}	H	VH	VH	VH	VH

Table 6: Priority Weight (in linguistic scale) of 1st level indices assigned by DMs

2nd level indices	Priority Weight (in linguistic scale) of 1st level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
C_1	VH	VH	H	VH	H
C_2	H	VH	VH	VH	VH
C_3	VH	H	VH	H	H

Table 7: Aggregated Fuzzy Priority Weight and Aggregated Fuzzy Rating of 3rd level indices

3nd level indices	Aggregated Fuzzy Priority Weight, w_{ijk}	Aggregated Fuzzy Rating, U_{ijk}
C_{111}	(0.48,0.82,0.84,0.92)	(0.48,0.82,0.84,0.92)
C_{112}	(0.74,0.84,0.88,0.94)	(0.60,0.70,0.72,0.82)
C_{113}	(0.68,0.78,0.82,0.90)	(0.42,0.52,0.54,0.64)
C_{121}	(0.54,0.64,0.66,0.76)	(0.62,0.72,0.76,0.86)
C_{122}	(0.48,0.82,0.84,0.92)	(0.66,0.76,0.78,0.88)
C_{123}	(0.74,0.84,0.88,0.94)	(0.42,0.52,0.54,0.64)
C_{131}	(0.48,0.58,0.66,0.76)	(0.24,0.34,0.42,0.52)
C_{132}	(0.60,0.70,0.72,0.82)	(0.46,0.56,0.62,0.72)
C_{141}	(0.48,0.82,0.84,0.92)	(0.66,0.76,0.78,0.88)
C_{142}	(0.74,0.84,0.88,0.94)	(0.70,0.80,0.80,0.90)
C_{211}	(0.68,0.78,0.82,0.90)	(0.46,0.56,0.62,0.72)
C_{212}	(0.54,0.64,0.66,0.76)	(0.48,0.82,0.84,0.92)
C_{213}	(0.48,0.82,0.84,0.92)	(0.68,0.78,0.82,0.90)
C_{214}	(0.48,0.82,0.84,0.92)	(0.32,0.42,0.46,0.56)
C_{215}	(0.52,0.62,0.68,0.78)	(0.62,0.72,0.76,0.86)
C_{221}	(0.60,0.70,0.72,0.82)	(0.64,0.74,0.74,0.84)
C_{222}	(0.48,0.82,0.84,0.92)	(0.42,0.52,0.54,0.64)
C_{223}	(0.74,0.84,0.88,0.94)	(0.24,0.34,0.42,0.52)
C_{224}	(0.48,0.82,0.84,0.92)	(0.46,0.56,0.62,0.72)
C_{225}	(0.54,0.64,0.66,0.76)	(0.66,0.76,0.78,0.88)
C_{311}	(0.48,0.82,0.84,0.92)	(0.66,0.76,0.78,0.88)
C_{312}	(0.74,0.84,0.88,0.94)	(0.44,0.54,0.58,0.68)
C_{313}	(0.48,0.58,0.66,0.76)	(0.48,0.82,0.84,0.92)
C_{314}	(0.60,0.70,0.72,0.82)	(0.68,0.78,0.82,0.90)
C_{315}	(0.48,0.82,0.84,0.92)	(0.32,0.42,0.46,0.56)
C_{321}	(0.76,0.86,0.92,0.96)	(0.62,0.72,0.76,0.86)
C_{322}	(0.48,0.82,0.84,0.92)	(0.66,0.76,0.78,0.88)
C_{323}	(0.56,0.66,0.70,0.80)	(0.40,0.50,0.50,0.60)
C_{331}	(0.70,0.80,0.80,0.90)	(0.24,0.34,0.42,0.52)
C_{332}	(0.74,0.84,0.88,0.94)	(0.46,0.56,0.62,0.72)
C_{333}	(0.48,0.58,0.66,0.76)	(0.62,0.72,0.76,0.86)

Table 8: Aggregated Fuzzy Priority Weight and Computed Fuzzy Rating of 2nd level indices

2nd level indices	Aggregated Fuzzy Priority Weight, w_{ij}	Aggregated Fuzzy Rating, U_{ij}
C_{11}	(0.74,0.84,0.88,0.94)	(0.27,0.66,0.73,1.15)
C_{12}	(0.76,0.86,0.92,0.96)	(0.37,0.64,0.71,1.17)
C_{13}	(0.48,0.82,0.84,0.92)	(0.25,0.43,0.57,0.91)
C_{14}	(0.60,0.70,0.72,0.82)	(0.68,0.73,0.82,1.36)
C_{21}	(0.70,0.80,0.80,0.90)	(0.32,0.62,0.72,1.24)
C_{22}	(0.74,0.84,0.88,0.94)	(0.31,0.55,0.63,1.19)
C_{31}	(0.52,0.62,0.68,0.78)	(0.33,0.62,0.72,1.22)
C_{32}	(0.74,0.84,0.88,0.94)	(0.38,0.64,0.73,1.16)
C_{33}	(0.78,0.88,0.96,0.98)	(0.31,0.50,0.62,0.94)

Table 9: Aggregated Fuzzy Priority Weight and Computed Fuzzy Rating of 1stlevel indices

1st level indices	Aggregated Fuzzy Priority Weight, w_i	Aggregated Fuzzy Rating, U_i
C_1	(0.76,0.86,0.92,0.96)	(0.28,0.59,0.73,1.61)
C_2	(0.78,0.88,0.96,0.98)	(0.28,0.57,0.69,1.55)
C_3	(0.74,0.84,0.88,0.94)	(0.26,0.54,0.74,1.45)

Table 11: Ranking order of 3rd level indices

3rd level indices	FPII	Crisp Value	Ranking Order
C_{111}	(0.250,0.148,0.134,0.074)	0.053	16
C_{112}	(0.156,0.112,0.086,0.049)	0.036	22
C_{113}	(0.134,0.114,0.097,0.064)	0.036	23
C_{121}	(0.285,0.259,0.258,0.206)	0.088	6
C_{122}	(0.343,0.137,0.125,0.070)	0.055	11
C_{123}	(0.109,0.083,0.065,0.038)	0.026	29
C_{131}	(0.125,0.143,0.143,0.125)	0.046	17
C_{132}	(0.184,0.168,0.174,0.130)	0.057	9
C_{141}	(0.343,0.137,0.125,0.070)	0.055	12
C_{142}	(0.182,0.128,0.096,0.054)	0.041	18
C_{211}	(0.147,0.123,0.112,0.072)	0.040	20
C_{212}	(0.221,0.295,0.286,0.221)	0.090	5
C_{213}	(0.354,0.140,0.131,0.072)	0.057	10
C_{214}	(0.166,0.076,0.074,0.045)	0.029	25
C_{215}	(0.298,0274,0.243,0.189)	0.091	4
C_{221}	(0.256,0.222,0.207,0.151)	0.075	8
C_{222}	(0.218,0.094,0.086,0.051)	0.037	21
C_{223}	(0.062,0.054,0.050,0.031)	0.017	31
C_{224}	(0.239,0.101,0.099,0.058)	0.041	19
C_{225}	(0.304,0.274,0.265,0.211)	0.093	3
C_{311}	(0.343,0.137,0125,0.070)	0.055	13
C_{312}	(0.114,0.086,0.070,0.041)	0.027	28
C_{313}	(0.250,0.344,0.286,0.221)	0.103	1
C_{314}	(0.272,0.234,0.230,0.162)	0.080	7
C_{315}	(0.166,0.076,0.074,0.045)	0.029	26
C_{321}	(0.149,0.101,0.061,0.034)	0.030	24
C_{322}	(0.343,0.137,0.125,0.070)	0.055	14
C_{323}	(0.176,0.170,0.150,0.120)	0.054	15
C_{331}	(0.072,0.068,0.084,0.052)	0.024	30
C_{332}	(0.120,0.090,0.074,0.043)	0.029	27
C_{333}	(0.322,0.302,0.258,0.206)	0.100	2