

A New Approach for Ranking of Fuzzy Numbers using the Incentre of Centroids

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Received 4 April 2014; accepted 11 April 2014

Abstract. The fuzzy set theory has been applied in many fields such as management, engineering etc. In modern management applications ranking using fuzzy numbers are the most important aspect in decision making process. This paper proposes a new method on the incentre of centroids and uses of Euclidean distance to ranking generalized hexagonal fuzzy numbers. We have used a ranking method for ordering fuzzy numbers based on areas and weights of generalized fuzzy numbers.

Keywords: Ranking, Hexagonal fuzzy numbers, Centroid, Area, Euclidean distance

AMS Mathematics Subject Classification (2010): 62F07, 03E72

1. Introduction

Ranking fuzzy number is used mainly in decision-making, data analysis, artificial intelligence and various other fields of operations research. In fuzzy environment ranking fuzzy numbers is a very important decision making procedure. Ranking fuzzy numbers were first proposed by Jain [9] for decision making in fuzzy situations by representing the ill defined quantity as a fuzzy set and he has given a procedure for multi aspect decision making using fuzzy sets in [10]. Some of these ranking methods have been compared and reviewed by Bortolan and Degani [3] and more recently by Chen and Hwang [5]. Lee and Li [14] proposed the comparison of fuzzy numbers. Liou and Wang [15] presented ranking fuzzy numbers with interval values. The centroids of fuzzy numbers have been examined recently and one of the most commonly used methods under the class of fuzzy scoring is the centroid point method. Centroid concept in ranking fuzzy number only started in 1980 by Yager [23]. Yager was the researcher who contributed the centroid concept in the ranking method and used the horizontal co-ordinate as x and the vertical y co-ordinates of the centroid point as the ranking index. Cheng [6] used a centroid based distance method to rank fuzzy numbers in 1998. Then Chu and Tsao [7] utilized the area between the centroid point and the origin to rank fuzzy numbers in 2002. Abbasbandy and Asady [1] suggested a sign distance method for ranking fuzzy numbers in 2006. Wang and Lee [22] proposed the revised method of ranking fuzzy numbers with an area

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between the centroid and original points in 2008. Since then several methods have been proposed by various researchers in [2,16-21] and ranking trapezoidal fuzzy numbers using area compensation distance method, maximizing and minimizing set decomposition principle and signed distance [4,24]. For an overview of fuzzy arithmetic theory one may refer [11-13] and the mean-value of fuzzy number in [8].

In this paper, a new method is proposed which is based on incentre of centroids to rank fuzzy quantities. In a hexagonal fuzzy number, the hexagonal is split into three plane figures where the first part being a Triangle and the second a Hexagon and the third once again a Triangle and then calculating the centroids of each plane figure followed by the incentre of these centroids and then finding the Euclidian distance. The proposed approach is compared with different existing approaches.

2. Preliminaries

Definition 2.1. Let X be a nonempty set. A fuzzy set A in X is characterized by its membership function $A: X \rightarrow [0,1]$, where $A(x)$ is interpreted as the degree of membership of element x in fuzzy A for each $x \in X$.

Definition 2.2. A fuzzy set is convex if

$$\mu_{\tilde{A}}(\lambda x_1 + (1-\lambda)x_2) \geq \min \{ \mu_{\tilde{A}}(x_1), \mu_{\tilde{A}}(x_2) \} \quad \forall x_1, x_2 \in X, \lambda \in [0,1]$$

Definition 2.3. The fuzzy set \tilde{A} is normal if $\text{height}(\tilde{A}) = 1$. In other words there exist at least one $x \in X$ such that $\mu_{\tilde{A}}(x) = 1$

Definition 2.4. A Fuzzy number “A” is a convex normalized fuzzy set on the real line \mathbb{R} such that:

- There exist at least one $x \in \mathbb{R}$ with $\mu_A(x) = 1$
- $\mu_A(x)$ is piecewise continuous.

3. Hexagonal Fuzzy Numbers

A fuzzy number \tilde{A}_H is a hexagonal fuzzy number denoted by $\tilde{A}_H(a_1, a_2, a_3, a_4, a_5, a_6)$ where $a_1, a_2, a_3, a_4, a_5, a_6$ are real numbers and its membership function $\mu_{\tilde{A}_H}(x)$ is given below.

Definition 3.1. A fuzzy set \tilde{A}_H defined on the universal set of real numbers \mathbb{R} is said to be generalized fuzzy number of its membership function has the following characteristics function

- (i) $P_1(u)$ is a bounded left continuous non decreasing function over $[0,0.5]$
- (ii) $Q_1(v)$ is a bounded left continuous non decreasing function over $[0.5,w]$
- (iii) $Q_2(v)$ is a bounded continuous non increasing function over $[w, 0.5]$
- (iv) $P_2(u)$ is a bounded left continuous non increasing function over $[0.5,0]$.

$$\mu_{\tilde{A}_H}(x) = \begin{cases} 0, & \text{for } x < a_1 \\ \frac{1}{2} \left(\frac{x - a_1}{a_2 - a_1} \right), & \text{for } a_1 \leq x \leq a_2 \\ \frac{1}{2} + \frac{1}{2} \left(\frac{x - a_2}{a_3 - a_2} \right), & \text{for } a_2 \leq x \leq a_3 \\ 1, & \text{for } a_3 \leq x \leq a_4 \\ \frac{1}{2} - \frac{1}{2} \left(\frac{x - a_4}{a_5 - a_4} \right), & \text{for } a_4 \leq x \leq a_5 \\ \frac{1}{2} \left(\frac{a_6 - x}{a_6 - a_5} \right), & \text{for } a_5 \leq x \leq a_6 \\ 0, & \text{for } x > a_6 \end{cases}$$

Remark 3.1.1. If $w = 1$, then the hexagonal fuzzy number is called a normal hexagonal fuzzy number.

Remark 3.1.2. Membership function $\mu_{\tilde{A}_H}(x)$ are continuous functions.

Definition 3.2. A positive hexagonal fuzzy number \tilde{A}_H is denoted by

$$\tilde{A}_H = (a_1, a_2, a_3, a_4, a_5, a_6) \text{ where all } a_i\text{'s} > 0 \text{ for all } i = 1, 2, 3, 4, 5, 6.$$

Definition 3.3. A negative hexagonal fuzzy number \tilde{A}_H is denoted by

$$\tilde{A}_H = (a_1, a_2, a_3, a_4, a_5, a_6) \text{ where all } a_i\text{'s} < 0 \text{ for all } i = 1, 2, 3, 4, 5, 6.$$

Definition 3.4. If $\tilde{A}_H = (a_1, a_2, a_3, a_4, a_5, a_6)$ is the hexagonal fuzzy number.

Then $-\tilde{A}_H = (-a_6, -a_5, -a_4, -a_3, -a_2, -a_1)$ which is the symmetric image of \tilde{A}_H .

3.5. Ordering of Hexagonal fuzzy number

Let $\tilde{A}_H = (a_1, a_2, a_3, a_4, a_5, a_6)$ and $\tilde{B}_H = (b_1, b_2, b_3, b_4, b_5, b_6)$ be in $F(\mathbb{R})$ be the set of all real hexagonal fuzzy numbers

- i) $\tilde{A}_H \approx \tilde{B}_H$ if and only if $a_i = b_i, i = 1, 2, 3, 4, 5, 6$
- ii) $\tilde{A}_H \leq \tilde{B}_H$ if and only if $a_i \leq b_i, i = 1, 2, 3, 4, 5, 6$
- iii) $\tilde{A}_H \geq \tilde{B}_H$ if and only if $a_i \geq b_i, i = 1, 2, 3, 4, 5, 6$.

3.6. Ranking of Hexagonal Fuzzy Numbers

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An efficient approach for comparing the fuzzy numbers is by the use of a ranking function $R : F(\mathbb{R}) \rightarrow \mathbb{R}$, where $F(\mathbb{R})$ is a set of fuzzy numbers defined on set of real numbers, which maps each fuzzy number into a real number, where a natural order exists. For any two hexagonal fuzzy numbers $\tilde{A}_H = (a_1, a_2, a_3, a_4, a_5, a_6)$ and $\tilde{B}_H = (b_1, b_2, b_3, b_4, b_5, b_6)$ we have the following comparison

- i) $\tilde{A}_H \approx \tilde{B}_H \Leftrightarrow R(\tilde{A}_H) = R(\tilde{B}_H)$
- ii) $\tilde{A}_H \geq \tilde{B}_H \Leftrightarrow R(\tilde{A}_H) \geq R(\tilde{B}_H)$
- iii) $\tilde{A}_H \leq \tilde{B}_H \Leftrightarrow R(\tilde{A}_H) \leq R(\tilde{B}_H)$

4. Proposed Method

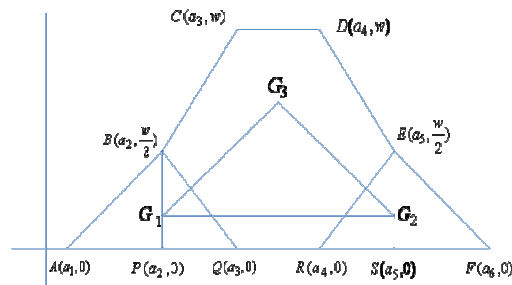


Fig.1 Generalized hexagonal fuzzy number

The centroid of a hexagonal fuzzy number is considered to be the balancing point of the hexagon (Fig.1). Divide the hexagonal into three plane figures. These three plane figures are a Triangle ABQ, Hexagon CDERQB and again a triangle REF respectively. Let the centroid of the three plane figures be G_1, G_2, G_3 , respectively. The incentre of the centroids G_1, G_2, G_3 is taken as the point of reference to define the ranking of generalized hexagonal fuzzy numbers. The reason for selecting this point as a point of reference is that each centroid points are balancing points of each individual plane figure and the incentre of these centroid points is a much more balancing point for a generalized hexagonal fuzzy number. Therefore, this point would be a better point than the centroid point of the hexagon. Consider a generalized hexagonal fuzzy number $\tilde{A}_H = (a_1, a_2, a_3, a_4, a_5, a_6; w)$. The centroid of the three plane figures are

$$G_1 = \left(\frac{a_1 + a_2 + a_3}{3}, \frac{w}{6} \right); \quad G_2 = \left(\frac{a_2 + 2a_3 + 2a_4 + a_5}{6}, \frac{w}{2} \right); \quad G_3 = \left(\frac{a_4 + a_5 + a_6}{3}, \frac{w}{6} \right);$$

respectively.

Equation of the line $\overline{G_1 G_3}$ is $y = \frac{w}{5}$ and G_2 does not lie on the line $G_1 G_3$. Therefore G_1, G_2 and G_3 are non-collinear and they form a triangle.

We define the incentre $I_{\tilde{A}_H}(x_0, y_0)$ of the triangle with vertices G_1, G_2 and G_3 of the generalized hexagonal fuzzy number $\tilde{A}_H = (a_1, a_2, a_3, a_4, a_5, a_6; w)$ as

$$I_{\tilde{A}_H}(x_0, y_0) = \left(\frac{\alpha_{\tilde{A}_H} \left(\frac{a_1 + a_2 + a_3}{3} \right) + \beta_{\tilde{A}_H} \left(\frac{a_2 + 2a_3 + a_4 + a_5}{6} \right) + \gamma_{\tilde{A}_H} \left(\frac{a_4 + a_5 + a_6}{3} \right)}{\alpha_{\tilde{A}_H} + \beta_{\tilde{A}_H} + \gamma_{\tilde{A}_H}}, \frac{\alpha_{\tilde{A}_H} \left(\frac{w}{6} \right) + \beta_{\tilde{A}_H} \left(\frac{w}{2} \right) + \gamma_{\tilde{A}_H} \left(\frac{w}{6} \right)}{\alpha_{\tilde{A}_H} + \beta_{\tilde{A}_H} + \gamma_{\tilde{A}_H}} \right) \quad (1)$$

where

$$\alpha_{\tilde{A}_H} = \frac{\sqrt{(a_4 + a_5 + 2a_6 - a_2 - 2a_3)^2 + 4w^2}}{6}, \quad \beta_{\tilde{A}_H} = \frac{\sqrt{(a_1 + a_2 + a_3 - a_4 - a_5 - a_6)^2}}{3}, \quad \gamma_{\tilde{A}_H} = \frac{\sqrt{(a_4 + a_5 - a_2 - 2a_1)^2 + 4w^2}}{6} \quad (2)$$

The ranking function of the generalized hexagonal fuzzy number

$\tilde{A}_H = (a_1, a_2, a_3, a_4, a_5, a_6; w)$, which maps the set of all fuzzy numbers to a set of real numbers

is defined as: $R(\tilde{A}_H) = \sqrt{x_0^2 + y_0^2}$ (3)

This is the Euclidean distance from the incentre of the centroids.

In sum, the rank of two fuzzy numbers \tilde{A}_H and \tilde{B}_H based on the incentre of the centroids is given in the following steps.

Let $\tilde{A}_H = (a_1, a_2, a_3, a_4, a_5, a_6; w_1)$ and $\tilde{B}_H = (b_1, b_2, b_3, b_4, b_5, b_6; w_2)$ be two generalized Hexagonal Fuzzy numbers then,

Step 1.

Find $\alpha_{\tilde{A}_H}, \beta_{\tilde{A}_H}, \gamma_{\tilde{A}_H}$ & $\alpha_{\tilde{B}_H}, \beta_{\tilde{B}_H}, \gamma_{\tilde{B}_H}$

Step 2.

Find $I_{\tilde{A}_H}(x_0, y_0)$ & $I_{\tilde{B}_H}(x_0, y_0)$

Step 3.

Find $R(\tilde{A}_H) = \sqrt{x_0^2 + y_0^2}$ & $R(\tilde{B}_H) = \sqrt{x_0^2 + y_0^2}$ and using the following for the ranking of fuzzy numbers

- i) If $R(\tilde{A}_H) > R(\tilde{B}_H)$, then $\tilde{A}_H > \tilde{B}_H$
- ii) If $R(\tilde{A}_H) < R(\tilde{B}_H)$ then $\tilde{A}_H \leq \tilde{B}_H$
- iii) If $R(\tilde{A}_H) \approx R(\tilde{B}_H)$ then $\tilde{A}_H \approx \tilde{B}_H$

Example 5.1. Let $\tilde{A}_H = (0.2, 0.3, 0.5, 0.6, 0.7, 0.9; 0.35)$ and

$\tilde{B}_H = (0.1, 0.2, 0.4, 0.5, 0.6, 0.9; 0.7)$ be two generalized fuzzy numbers, then,

Step 1:

$$\alpha_{\tilde{A}_H} = \frac{\sqrt{(a_4 + a_5 + 2a_6 - a_2 - 2a_3)^2 + 4w^2}}{6} = \frac{\sqrt{(0.6 + 0.7 + 2(0.9) - 0.3 - 2(0.5))^2 + 4(0.35)^2}}{6} = 0.32$$

$$\alpha_{\tilde{B}_H} = \frac{\sqrt{(0.5 + 0.6 + 2(0.9) - 0.2 - 2(0.4))^2 + 4(0.7)^2}}{6} = 0.39$$

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$$\beta_{\tilde{A}_H} = \frac{\sqrt{(a_1 + a_2 + a_3 - a_4 - a_5 - a_6)^2}}{3} = \frac{\sqrt{(0.2 + 0.3 + 0.5 - 0.6 - 0.7 - 0.9)^2}}{3} = 0.4$$

$$\beta_{\tilde{B}_H} = \frac{\sqrt{(0.1 + 0.2 + 0.4 - 0.5 - 0.6 - 0.9)^2}}{3} = 0.43$$

$$\gamma_{\tilde{A}_H} = \frac{\sqrt{(a_4 + a_5 - a_2 - 2a_1)^2 + 4w^2}}{6} = \frac{\sqrt{(0.6 + 0.7 - 0.3 - 2(0.2))^2 + 4(0.35)^2}}{6} = 0.15$$

$$\gamma_{\tilde{B}_H} = \frac{\sqrt{(0.5 + 0.6 - 0.2 - 2(0.1))^2 + 4(0.7)^2}}{6} = 0.26$$

Step 2:

$$I_{\tilde{A}_H}(\tilde{x}_0, \tilde{y}_0) = \left(\frac{0.32\left(\frac{0.2+0.3+0.5}{3}\right) + 0.4\left(\frac{0.3+1+0.6+0.7}{6}\right) + 0.15\left(\frac{0.6+0.7+0.9}{3}\right)}{0.32+0.4+0.15}, \frac{0.32\left(\frac{0.35}{6}\right) + 0.4\left(\frac{0.35}{2}\right) + 0.15\left(\frac{0.35}{6}\right)}{0.32+0.4+0.15} \right) = (0.43, 0.1)$$

$$I_{\tilde{B}_H}(\tilde{x}_0, \tilde{y}_0) = \left(\frac{0.39\left(\frac{0.1+0.2+0.4}{3}\right) + 0.43\left(\frac{0.2+0.8+0.5+0.6}{6}\right) + 0.26\left(\frac{0.5+0.6+0.9}{3}\right)}{0.39+0.43+0.26}, \frac{0.39\left(\frac{0.7}{6}\right) + 0.43\left(\frac{0.7}{2}\right) + 0.26\left(\frac{0.7}{6}\right)}{0.39+0.43+0.26} \right) = (0.37, 0.2)$$

Step 3:

$$R_{\tilde{A}_H} = \sqrt{(0.43)^2 + (0.11)^2} = 0.44 \quad R_{\tilde{B}_H} = \sqrt{(0.37)^2 + (0.20)^2} = 0.42$$

So $R_{\tilde{A}_H} > R_{\tilde{B}_H}$ then, $\tilde{A}_H > \tilde{B}_H$

Example 5.2. Let $\tilde{A}_H = (0.1, 0.2, 0.4, 0.6, 0.7, 0.9; 1)$ and $\tilde{B}_H = (0.2, 0.4, 0.6, 0.7, 0.8, 0.9; 1)$ be two generalized fuzzy numbers. Then,

Step 1:

$$\alpha_{\tilde{A}_H} = \frac{\sqrt{(a_4 + a_5 + 2a_6 - a_2 - 2a_3)^2 + 4w^2}}{6} = \frac{\sqrt{(0.6 + 0.7 + 2(0.9) - 0.2 - 2(0.4))^2 + 4}}{6} = 0.47$$

$$\alpha_{\tilde{B}_H} = \frac{\sqrt{(0.7 + 0.8 + 2(0.9) - 0.3 - 2(0.6))^2 + 4}}{6} = 0.44$$

$$\beta_{\tilde{A}_H} = \frac{\sqrt{(a_1 + a_2 + a_3 - a_4 - a_5 - a_6)^2}}{3} = \frac{\sqrt{(0.1 + 0.2 + 0.4 - 0.6 - 0.7 - 0.9)^2}}{3} = 0.5$$

$$\beta_{\tilde{B}_H} = \frac{\sqrt{(0.2 + 0.3 + 0.6 - 0.7 - 0.8 - 0.9)^2}}{3} = 0.4$$

$$\gamma_{\tilde{A}_H} = \frac{\sqrt{(a_4 + a_5 - a_2 - 2a_1)^2 + 4w^2}}{6} = \frac{\sqrt{(0.6 + 0.7 - 0.2 - 2(0.1))^2 + 4}}{6} = 0.36$$

$$\gamma_{\tilde{B}_H} = \frac{\sqrt{(0.7 + 0.8 - 0.3 - 2(0.2))^2 + 4}}{6} = 0.35$$

Step 2:

$$I_{\tilde{A}_H}(\tilde{x}_0, \tilde{y}_0) = \left(\frac{0.47\left(\frac{0.1+0.2+0.3}{3}\right) + 0.5\left(\frac{0.2+0.8+0.6+0.7}{6}\right) + 0.36\left(\frac{0.6+0.7+0.9}{3}\right)}{0.47+0.5+0.36}, \frac{0.47\left(\frac{1}{6}\right) + 0.5\left(\frac{1}{2}\right) + 0.36\left(\frac{1}{6}\right)}{0.47+0.5+0.36} \right) = (0.40, 0.27)$$

$$I_{\tilde{B}_H}(\tilde{x}_0, \tilde{y}_0) = \left(\frac{0.44\left(\frac{0.2+0.3+0.6}{3}\right) + 0.4\left(\frac{0.3+0.12+0.7+0.8}{6}\right) + 0.35\left(\frac{0.7+0.8+0.9}{3}\right)}{0.44+0.4+0.35}, \frac{0.44\left(\frac{1}{6}\right) + 0.4\left(\frac{1}{2}\right) + 0.35\left(\frac{1}{6}\right)}{0.44+0.4+0.35} \right) = (0.53, 0.26)$$

Step 3:

$$R_{\tilde{A}_H} = \sqrt{(0.40)^2 + (0.27)^2} = 0.48 \quad R_{\tilde{B}_H} = \sqrt{(0.53)^2 + (0.26)^2} = 0.59$$

So $R_{\tilde{A}_H} < R_{\tilde{B}_H}$ then, $\tilde{A}_H < \tilde{B}_H$

Example I of T.C.Chu and C.T.Tsao Approach:

Let $\tilde{A}_H = (0.2, 0.3, 0.5, 0.6, 0.7, 0.9; 0.35)$ and $\tilde{B}_H = (0.1, 0.2, 0.4, 0.5, 0.6, 0.9; 0.7)$ be two generalized fuzzy numbers, then

$$\bar{x}(\tilde{A}_H) = \frac{\int_{a_1}^{a_2} xf_A^L dx + \int_{a_2}^{a_3} xf_A^L dx + \int_{a_3}^{a_4} x dx + \int_{a_4}^{a_5} (xf_A^R) dx + \int_{a_5}^{a_6} (xf_A^R) dx}{\int_{a_1}^{a_2} f_A^L dx + \int_{a_2}^{a_3} f_A^L dx + \int_{a_3}^{a_4} dx + \int_{a_4}^{a_5} f_A^R dx + \int_{a_5}^{a_6} f_A^R dx}$$

$$\bar{y}(\tilde{A}_H) = \frac{\int_0^{\frac{w}{2}} yg_A^L dy + \int_{\frac{w}{2}}^w yg_A^L dy + \int_0^{\frac{w}{2}} yg_A^R dy + \int_{\frac{w}{2}}^w (yg_A^R) dy}{\int_0^{\frac{w}{2}} g_A^L dy + \int_{\frac{w}{2}}^w g_A^L dy + \int_0^{\frac{w}{2}} g_A^R dy + \int_{\frac{w}{2}}^w g_A^R dy}$$

$$\bar{x}(\tilde{A}_H) = 0.5, \quad \bar{y}(\tilde{A}_H) = 0.49$$

Similarly,

$$\bar{x}(\tilde{B}_H) = 0.57, \quad \bar{y}(\tilde{B}_H) = 0.58$$

$$S(\tilde{A}_H) = 0.24, S(\tilde{B}_H) = 0.18$$

$S(\tilde{A}_H) > S(\tilde{B}_H)$ then $\tilde{A}_H > \tilde{B}_H$

Example II of T.C.Chu and C.T.Tsao:

Let $\tilde{A}_H = (0.1, 0.2, 0.4, 0.6, 0.7, 0.9; 1)$ and $\tilde{B}_H = (0.2, 0.3, 0.6, 0.7, 0.8, 0.9; 1)$ be two generalized fuzzy numbers

$$\bar{x}(\tilde{A}_H) = \frac{\int_{a_1}^{a_2} xf_A^L dx + \int_{a_2}^{a_3} xf_A^L dx + \int_{a_3}^{a_4} x dx + \int_{a_4}^{a_5} (xf_A^R) dx + \int_{a_5}^{a_6} (xf_A^R) dx}{\int_{a_1}^{a_2} f_A^L dx + \int_{a_2}^{a_3} f_A^L dx + \int_{a_3}^{a_4} dx + \int_{a_4}^{a_5} f_A^R dx + \int_{a_5}^{a_6} f_A^R dx}$$

$$\bar{x}(\tilde{A}_H) = 0.45, \quad \bar{y}(\tilde{A}_H) = 0.8$$

Similarly,

$$\bar{x}(\tilde{B}_H) = 0.55, \quad \bar{y}(\tilde{B}_H) = 0.51$$

$$S(\tilde{A}_H) = 0.36, S(\tilde{B}_H) = 0.28$$

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$S(\tilde{A}_H) > S(\tilde{B}_H)$ then $\tilde{A}_H > \tilde{B}_H$

Approaches	Chu T.C. and Tsao .C T.[7]	Proposed approach in Hexagonal
Ex 1	$\tilde{A}_H > \tilde{B}_H$	$\tilde{A}_H > \tilde{B}_H$
Ex2	$\tilde{A}_H > \tilde{B}_H$	$\tilde{A}_H < \tilde{B}_H$

6. Conclusion

In this method, splitting the generalized hexagonal fuzzy numbers into three plane figures and then calculating the centroid of each plane figure followed by the incenter of the centroid and then finding the Euclidian distance and the same problem was compared with Chu and Tsao [7] method with comparative examples. The main advantage of the proposed approach is that this provides the correct ordering of generalized and normal hexagonal fuzzy numbers and also easy to apply in the real life problems. Presently in real life there are many situations and parameters with more criteria, so in order to get a comprehensive result this method is very useful.

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