iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** III **Month of publication:** March 2025

DOI: https://doi.org/10.22214/ijraset.2025.67959

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue III Mar 2025- Available at www.ijraset.com

Critical Path Problem in Fuzzy Environment Using Hexagonal Fuzzy Numbers

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Abstract: Fuzzy number ranking is crucial in optimisation approaches such assignment difficulties, transportation challenges, project scheduling, artificial intelligence,data analysis, network flow analysis, unpredictability in organisational economics, and so forth.A novel fuzzy ranking in hexagonal fuzzy numbers is presented in this work. In the project schedule, the duration of each task is represented by a hexagonal fuzzy number. Every hexagonal fuzzy number is converted into a crisp number (normal number) via the new ranking function. We developed a new algorithm to compute the fuzzy critical route.A numerical example is provided to illustrate these methods.
Keywords: Activity duration, centroid, fuzzy ranking, fuzzy critical path, fuzzy number, project schedule.

I. INTRODUCTION

One of the most crucial ideas in network research is the critical path approach.By forming networks and determining the earliest start and conclusion dates for each task, it helps to resolve project difficulties.Additionally, it is a method for scheduling a group of project networks.Additionally, it is typically linked to the Program Evaluation and Review Technique (PERT). 'Fuzzy logic' was proposed by Zadeh [22] and takes into account errors and inconsistencies. Numerous scholars have employed fuzzy numbers in a variety of ways, including Pentagonal fuzzy numbers, Trapezoidal fuzzy numbers, and fuzzy triangular numbers. Triangular or trapezoidal fuzzy numbers are typically the variables that characterise information ambiguity or vagueness in many real-world scenarios. Based on Zadeh's extension approach, Lee et al. [10] generalised the addition, subtraction, multiplication, and division results and introduced Pentagonal fuzzy numbers. Pathinadhan et al. [11] introduced a novel form of the non-normal generalized pentagonal fuzzy number, and some of its arithmetic operations, centroid, and median were examined. The ranking approach was used by Siji et al. [15] to tackle network problems involving Pentagonal Intuitionistic fuzzy numbers. The fuzzy TOPSIS method was used by Arokiamary et al. [1] to determine the critical path analysis in a project network. [16] Uthra et al. [19] defined a Generalized Intuitionistic Pentagonal Fuzzy Number and developed a new ranking formula. A new ranking on Hexagonal fuzzy numbers was proposed by Sudha and Revathi [13] in 2016. When the period of each activity is written as a Linear Hexagonal fuzzy number, Selvakumari and Sowmiya [14]presented a method in 2017 for finding fuzzy critical pathways using Pascal's triangle graded mean integration. In 2018, Rajendran et al. [12] Developed a new ranking for generalised hexagonal fuzzy numbers, and the results were compared to fuzzy hexagonal number magnitude. Hexagonal fuzzy number cardinality, which is utilised to comprehend a method for classifying Hexagonal fuzzy numbers, was introduced by Leela-Apiradee et al. In 2020. They also suggested a ranking methodology for Hexagonal fuzzy numbers, particularly based on their potential mean values. In order to convert a fuzzy hexagonal number into a crisp number and determine its relevance for resolving decision-making issues, Avishek et al. [7] presented a novel ranking and defuzzification concept in 2020. Using the centroid formula of triangle and rectangle and taking into account the distance from the origin to the centroid centroided, Thirupathi et al. [17] introduced a novel raking method in 2020 that relies on the fuzzy hexagonal number. In the context of hexagonal fuzzy numbers, it is seen as a rating.Thangaraj Beaula and Vijaya[4-6] have adopted different fuzzy numbers and ranking methods to solve critical path problems. Vijaya et al. have used Pythagorean Fuzzy numbers and Neutrosophic Fuzzy numbers to find the solution of Decision making problem and critical path problems.Vijaya et al have used complex Fermatean Neutrosophic fuzzy sets to solve decision making problem.Vijaya V, Said Broumi, & Manikandan H. [21] (2025). ComplexFermatean Neutrosophic Sets and their Applications in Decision Making. Neutrosophic Sets and Systems, 81, 827-839. In this paper, we have solved a fuzzy critical path problem using hexagonal fuzzy numbers.

II. BASIC DEFINITIONS

In this section we look at a few definitions.

Definition 2.1

A fuzzy set is characterized by membership function mapping element of the domain, space of the universe of discourse X to the unit interval [0,] i.e., $A = \{x, \mu_{\tilde{A}}(x); x \in X\}$

Here $\mu_{\tilde{A}}(x): x \to [0,1]$ is the mapping called the degree of membership function of the fuzzy set A and $\mu_{\tilde{A}}(x)$ is called membership value of x belongs to X in the fuzzy set A, these membership function are represented by real numbers ranging from [0,1].

Definition 2.2

A Fuzzy set A of the real line R with membership function $\mu_{\tilde{A}}(x) =: R \to [0,1]$is called fuzzy number. If

(a) $\tilde{A}$must be normal and convex fuzzy set.

(b) The support of$\tilde{A}$ be bounded.

(c) $\alpha.\tilde{A}$ must be closed interval for every a in [0,1]

Definition 2.3

A fuzzy set $\tilde{A} = (a, b, c, d, \omega)$ is defined on universal set of real number if its membership function has the following attributes

(a) $\mu_{\tilde{A}}(x): R \to [0,1]$is continues.

(b) $\mu_{\tilde{A}}(x) = 0$ for all$x \in [-\infty, a] \cup [d, \infty]$

(c) $\mu_{\tilde{A}}(x)$ is strictly increasing on [a,b] and strictly decreasing on [c,d]

(d) $\mu_{\tilde{A}}(x) = \omega$ for all x∈[b,c] where $0 \leq \omega \leq 1$

Definition 2.4

A Pentagonal fuzzy number $\tilde{A}_p = (p_1, p_2, p_3, p_4, p_5)$ where p_1, p_2, p_3, p_4, p_5 real numbers and its membership function is defined by

$$\mu_{\tilde{A}_p}(x) = \begin{cases} \frac{1}{2}\left(\frac{x-p_1}{p_2-p_1}\right); & for \quad p_1 \leq x \leq p_2 \\ \frac{1}{2} + \frac{1}{2}\left(\frac{x-p_2}{p_3-p_2}\right); & for \; p_2 \leq x \leq p_3 \\ 1 - \frac{1}{2}\left(\frac{x-p_3}{p_4-p_3}\right); & for \; p_3 \leq x \leq p_4 \\ \frac{1}{2}\left(\frac{p_5-x}{p_5-p_4}\right); & for \; p_4 \leq x \leq p_5 \\ 0; & otherwise \end{cases}$$

The Pentagonal fuzzy number diagram represented in the Fig. 1.

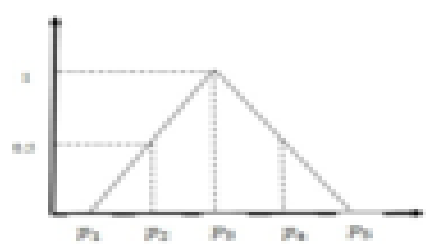


Fig. 1Pentagonal Fuzzy Number

Definition 2.5

A generalized Pentagonal fuzzy number $\tilde{A}_p$ its membership function is expressed as

$$\mu_{\tilde{A}}(x) = \begin{cases} \frac{\omega}{2}\left(\frac{x-p_1}{p_2-p_1}\right); & for\ p_1 \le x \le p_2 \\ \frac{1}{2}+\frac{\omega}{2}\left(\frac{x-p_2}{p_3-p_2}\right); & for\ p_2 \le x \le p_3 \\ 1-\frac{\omega}{2}\left(\frac{x-p_3}{p_4-p_3}\right); & for\ p_3 \le x \le p_4 \\ \frac{1}{2}\left(\frac{p_5-x}{p_5-p_4}\right); & for\ p_4 \le x \le p_5 \\ 0; & otherwise \end{cases}$$

A generalized Pentagonal fuzzy number represented in the Fig. 2.

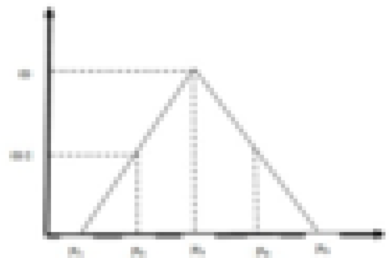


Fig. 2 Generalized Pentagonal Fuzzy Number

Definition 2.6

A fuzzy number$\tilde{A}_H$ is a Hexagonal fuzzy number represented by$\tilde{A}_H = (p_1, p_2, p_3, p_4, p_5, p_6,)$ where p,q,r,s,t,u are real numbers and its membership function $\mu_{\tilde{A}_H}(x)$is given by

$$\mu_{\tilde{A}_H}(x) = \begin{cases} \frac{1}{2}\left(\frac{x-p_1}{p_2-p_1}\right), & for\ p_1 \le x \le p_2 \\ \frac{1}{2}+\frac{1}{2}\left(\frac{x-p_2}{p_3-p_2}\right), & for\ p_2 \le x \le p_3 \\ 1, & for\ p_3 \le x \le p_4 \\ 1-\frac{1}{2}\left(\frac{x-p_4}{p_5-p_4}\right), & for\ p_4 \le x \le p_5 \\ \frac{1}{2}\left(\frac{p_6-x}{p_6-p_5}\right), & for\ p_5 \le x \le p_6 \\ 0, & otherwise \end{cases}$$

Definition 2.7

A Generalized Hexagonal Fuzzy number represented by $\tilde{A}_H = (p_1, p_2, p_3, p_4, p_5, p_6, \omega)$
where a,b,c,d,e,f,g are real numbers and its membership $\mu_{\tilde{A}_H}$ is defined by

$$\mu_{\tilde{A}_H}(x) = \begin{cases} \frac{\omega}{2}\left(\frac{x-p_1}{p_2-p_1}\right); & for\ p_1 \le x \le p_2 \\ \frac{1}{2}+\frac{\omega}{2}\left(\frac{x-p_2}{p_3-p_2}\right); & for\ p_2 \le x \le p_3 \\ \omega; & for\ p_3 \le x \le p_4 \\ 1-\frac{\omega}{2}\left(\frac{x-p_4}{p_5-p_4}\right); & for\ p_4 \le x \le p_5 \\ \frac{\omega}{2}\left(\frac{p_6-x}{p_6-p_5}\right); & for\ p_5 \le x \le p_6 \\ 0; & otherwise \end{cases}$$

A Generalized Hexagonal fuzzy number represented in the Fig. 3.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue III Mar 2025- Available at www.ijraset.com

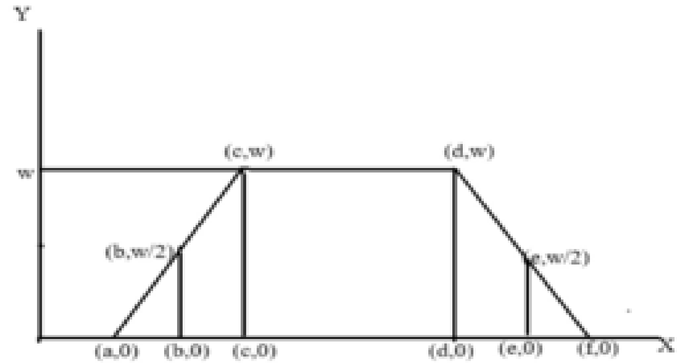


Fig.3Generalized Hexagonal Fuzzy Number

III. METHODOLOGY

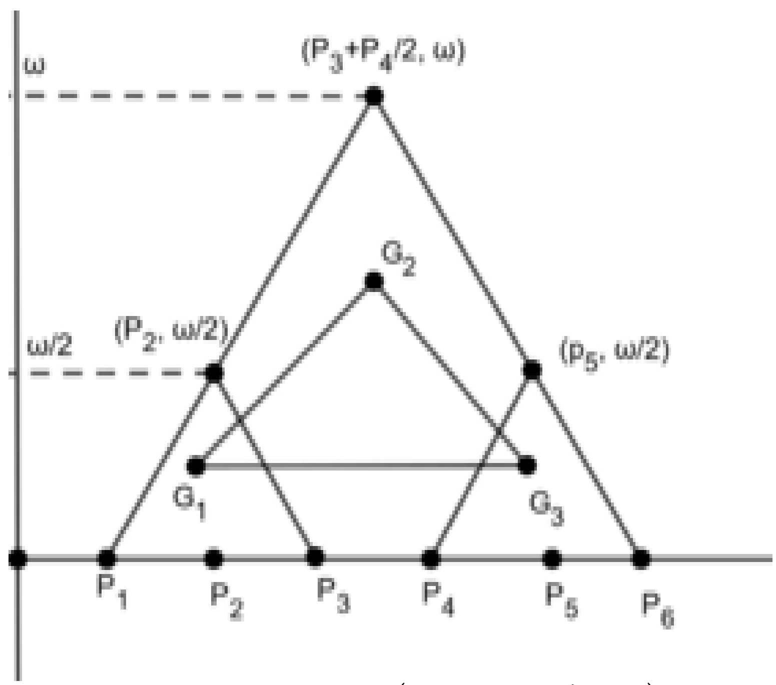
This section, proposed a new ranking function in hexagonal fuzzy numbers.

Divide the pentagon into two triangles and one rectangle.Let G_1, G_2, and G_3 be the centroid of the three plane figures respectively.The centroid of a fuzzy hexagon number is supposed to indicate the hexagon's balancing point.

The proposal ranking in a Pentagonal fuzzy numberconverted into Hexagonal fuzzy numbersdiagram is represented in Fig. 2.

To determine the ranking of a Generalized hexagonal fuzzy number, the in centre of the G_1, G_2 and G_3 is used as a point of reference.

Consider thegeneralized hexagonal fuzzy number$\tilde{A}_H = (p_1, p_2, p_3, p_4, p_5, p_6, \omega)$



The three plane figures centroid is$G_1 = \left(\frac{p_1+p_2+p_3}{3}, \frac{\omega}{6}\right)$, $G_2 = \left(\frac{p_2+p_3+p_4+p_5+\frac{p_3+p_4}{2}}{5}, \frac{2\omega}{5}\right)$,

$G_3 = \left(\frac{p_4+p_5+p_6}{3}, \frac{\omega}{6}\right)$

The centroid of G_1, G_2 and G_3 is$\left(\frac{10p_1+16p_2+19p_3+19p_4+16p_5+10p_6}{90}, \frac{11\omega}{45}\right)$

$$G_{\tilde{A}_H}(x_0, y_0) = \left(\frac{10p_1 + 16p_2 + 19p_3 + 19p_4 + 16p_5 + 10p_6}{90}, \frac{11\omega}{45}\right)$$

The in centre of the centroid with Euclidean distance is;

$$\sqrt{x_0^2 + y_0^2}$$

Consider that the centroid's with Euclidean distance is a new ranking function in the Generalized Hexagonal fuzzy numbers. Therefore, a new ranking in the Generalized Hexagonal Fuzzy Number is;

$$R(\tilde{A}_H) = \sqrt{x_0^2 + y_0^2}$$

A. Fuzzy Critical Path Analysis

The primary objective of the fuzzy critical path is to estimate the total project duration and assign start and finish dates to all project activities. This makes it possible to compare the actual progress to the estimated duration.

The following fuzzy factors should be known to prepare the project schedule.

(i) Project completion time

(ii) Each activity's earliest and latest times

(iii) Critical activities and the critical path

(iv) Float for each activity (ie.,the time required to complete a non- critical activity can be delayed without affecting the overall project completion time)

1) Notations

$FE\tilde{S}_{ij}$ =Earliest start of time of an activity (i,j)

$FL\tilde{S}_{ij}$ =Latest start time of an activity (i,j)

$FE\tilde{F}_{ij}$ =Earliest finish time of an activity (i,j)

$FL\tilde{F}_{ij}$ =Latest finish time of an activity (i.j)

$F\tilde{t}_{ij}$ =Total duration of an activity (i,j)

$FT\tilde{F}_{ij}$ =Total float of an activity (i,j)

2) Algorithm for Finding Fuzzy Critical Path

Step 1: Construct a fuzzy project network with predecessor and successor events.

Step 2: Express every activity as Hexagonal fuzzy number.

Step 3:Transformed every Hexagonal fuzzy number as a crisp number using new ranking function.

Step 4: Calculated Earliest Start Time,$FE\tilde{S}_{ij} = \max\{FE\tilde{S}_{ij} + t_{ij}\}$, number of preceding nodes.

Step 5: Calculate Earliest Finish Time,$FE\tilde{F}_{ij} = FE\tilde{S}_i + t_{ij}$.

Step 6:Calculate Latest Finish Time, $FL\tilde{F}_{ij} = \min\{FL\tilde{F}_{ij} - t_{ij}\}$=number of succeeding nodes.

Step 7:Calculate Latest Start Time, $FL\tilde{S}_{ij} = FL\tilde{F}_{ij} - t_{ij}$.

Step 8: Calculate Total float, $FT\tilde{F}_{ij} = FL\tilde{F}_{ij} - FE\tilde{F}_{ij} \; or \; FL\tilde{S}_{ij} - FE\tilde{S}_{ij}$.

IV. NUMERICAL EXAMPLE

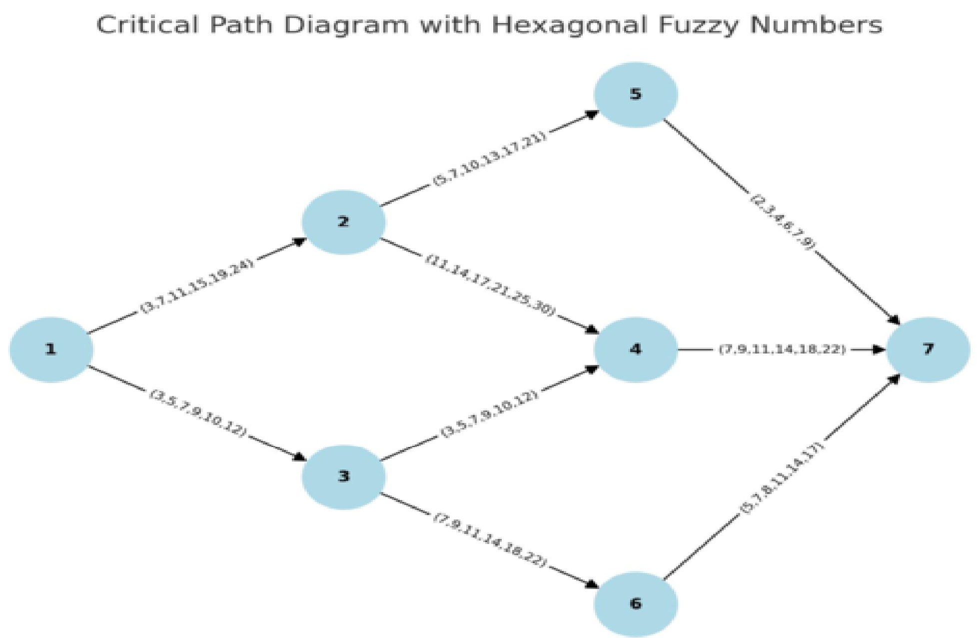
Consider the following fuzzy project network, in which the Hexagonal Fuzzy Numbers represents each activity. The fuzzy project network has seven nodes and nine nodes.This example shows how to schedule a construction project using a Project Network.My objective is to analyze themaximum path that is the essential critical path for the construction process.

ACTIVITY	DURATION
1-2	(3,7,11,15,19,24)
1-3	(3,5,7,9,10,12)
2-4	(11,14,17,21,25,30)
3-4	(3,5,7,9,10,12)
2-5	(5,7,10,13,16,21)

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue III Mar 2025- Available at www.ijraset.com

3-6	(7,9,11,14,18,22)
4-7	(7,9,11,14,18,22)
5-7	(2,3,4,6,7,9)
6-7	(5,7,8,11,14,17)

Solution :
Based on the activity and activity duration using the hexagonal fuzzy numbers. The network diagram is following:



A. *Expected time of activities*

Based on the proposed ranking method, all the activity duration changed into crisp values using the formula

$$G_{\tilde{A}_H}(x_0, y_0) = \left(\frac{10p_1 + 16p_2 + 19p_3 + 19p_4 + 16p_5 + 10p_6}{90}, \frac{11\omega}{45}\right)$$

$$R_{\tilde{A}_H} = \sqrt{x_0^2 + y_0^2}$$

Using the above formula,
We have find, R(3,7,11,15,19,24)

$$G_{\tilde{A}_H}(x_0, y_0) = \left(\frac{10(3) + 16(7) + 19(11) + 19(15) + 16(19) + 10(24)}{90}, \frac{11}{45}\right)$$

$$= \left(\frac{30 + 112 + 209 + 285 + 304 + 240}{90}, 0.2444\right)$$

$$= \left(\frac{1180}{90}, 0.2444\right)$$

$G_{\tilde{A}_H}(x_0, y_0) = (13.1111, 0.2444)$ *where* $x_0 = 13.1111$, $y_0 = 0.2444$

$$R(3,7,11,15,19,24) = \sqrt{(13.1111)^2 + (0.2444)^2}$$

$$= \sqrt{171.9009 + 0.0597}$$

$$= \sqrt{171.9606}$$

$R(3,7,11,15,19,24) = 13.1134$

Similarly, find all the activities

$R(3,5,7,9,10,12) = 7.715$
$R(11,14,17,21,25,30) = 19.5126$
$R(3,5,7,9,10,12) = 7.715$
$R(5,7,10,13,17,21) = 12.0136$
$R(7,9,11,14,18,22) = 13.0801$
$R(7,9,11,14,18,22) = 13.0801$
$R(2,3,4,6,7,9) = 5.1169$

$$R(5,7,8,11,14,17) = 10.1918$$

Hexagonal fuzzy numbers transformed into activity duration by proposed ranking function. This activity duration is taken as the time between the nodes, and the fuzzy critical path is calculated by applying an algorithm. The Expected time of activities represented in the table.

ACTIVITY	HEXAGONAL FUZZY NUMBER	EXPECTED TIME
1-2	(3,7,11,15,19,24)	13.1134
1-3	(3,5,7,9,10,12)	7.715
2-4	(11,14,17,21,25,30)	19.5126
3-4	(3,5,7,8,10,12)	7.715
2-5	(5,7,10,13,17,21)	12.0136
3-6	(7,9,11,14,18,22)	13.0801
4-7	(7,9,11,14,18,22)	13.0801
5-7	(2,3,4,6,7,9)	5.1169
6-7	(5,7,8,11,14,17)	10.1918

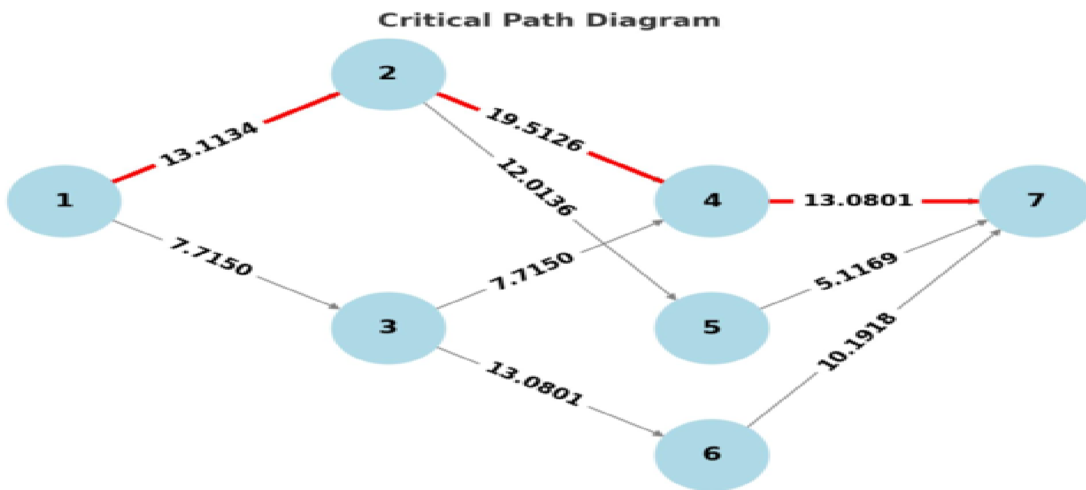
B. Earliest, Latest times and Total float fuzzy activities

Computedthe Earliest, Latest times and Total float formulas mentioned in Step 4, step 5, step 6, step 7 and step 8 respectively.The Earliest, Latest times and Total Float of activities represented in the table.

ACTIVITY	$\boldsymbol{F\tilde{t}_{ij}}$	$\boldsymbol{FE\tilde{S}_{ij}}$	$\boldsymbol{FE\tilde{F}_{ij}}$	$\boldsymbol{FL\tilde{S}_{ij}}$	$\boldsymbol{FL\tilde{F}_{ij}}$	$\boldsymbol{FT\tilde{F}_{ij}}$
1-2	13.1134	0	13.1134	0	13.1134	**0**
1-3	7.715	0	7.715	14.7192	22.4342	14.7192
2-4	19.5126	13.1134	32.626	13.1134	32.626	**0**
3-4	7.715	7.715	15.43	24.911	32.626	17.196
2-5	12.0136	13.1134	25.127	28.5756	40.5892	15.4622
3-6	13.0801	7.715	20.7951	22.4342	35.5143	14.7192
4-7	13.0801	32.626	45.7061	32.626	45.7061	**0**
5-7	5.1169	25.127	30.2439	40.5892	45.7061	15.4622
6-7	10.1918	20.7951	30.9869	35.5143	45.7061	14.7192

C. Results

According to the fuzzy total float, the fuzzy critical activities are1→2, 2→ 4, 4 → 7.
Therefore, the critical path of the fuzzy project network is**1→2→4→7.**
Hence the total duration of the project network is 45.7061≈46.



V. CONCLUSIONS

This paper introduced a new ranking function in Hexagonal fuzzy numbers.The proposed ranking function is derived from the centroid of Hexagonal Fuzzy Numbers.In the network, every activity period is expressed by a Hexagonal Fuzzy Numbers.The duration of every activity is transformed into the normal number or crisp number by a new ranking function.This normal number is considered the expected time of activity.The fuzzy critical path algorithm was used to identify the fuzzy critical path and project completion time.The proposal ranking can also be applied to more complex project networks in the real world.We can apply the ranking function of hexagonal fuzzy numbers to solve game problems and transportation problems.

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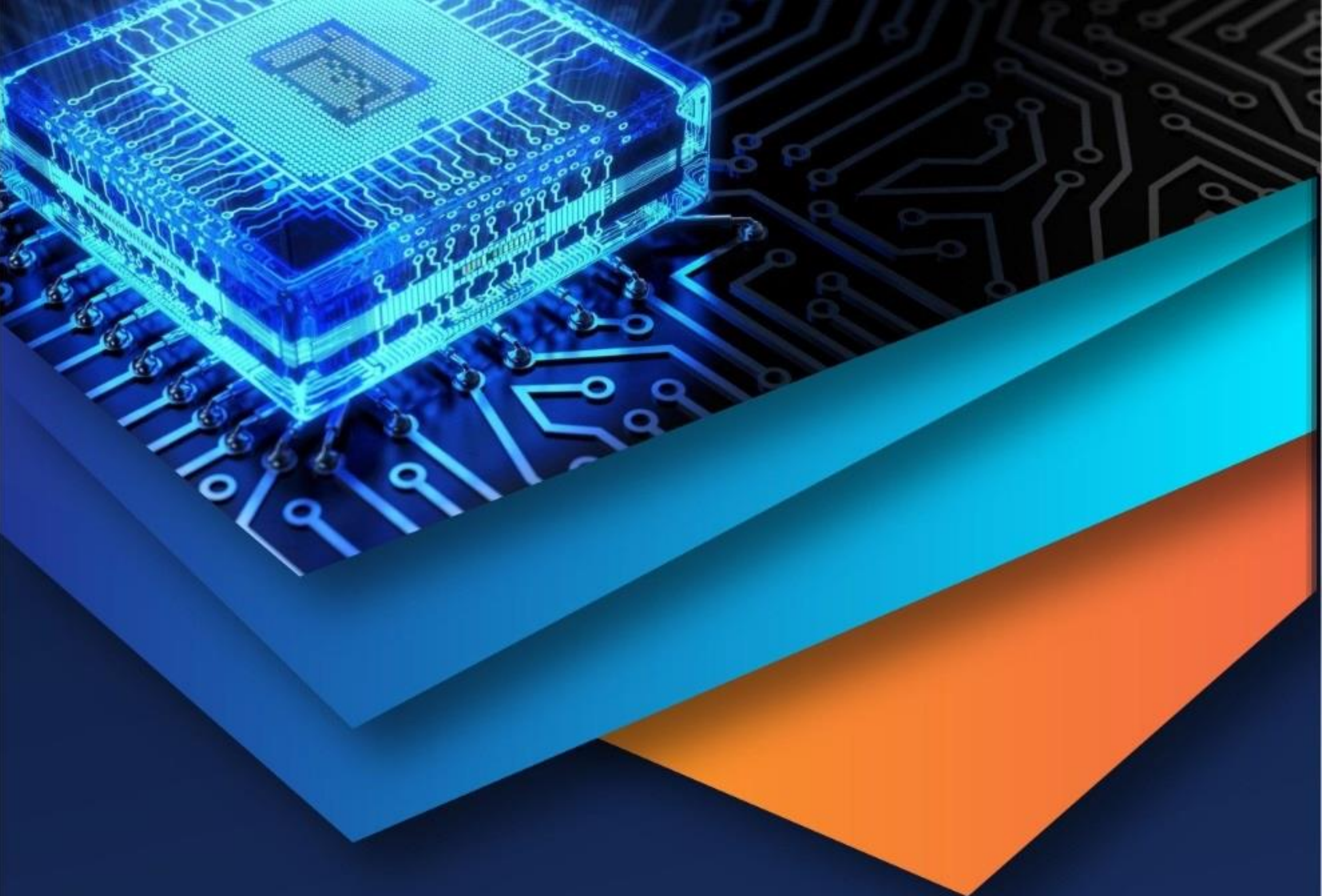

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