COMPUTATION OF SHORTEST PATH IN A NETWORK USING TRAPEZOIDAL FUZZY NEUTROSOPHIC NUMBER

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Abstract:- In this paper, we develop a new approach to deal with neutrosophic shortest path problem in a network in which each edge weight is represented as trapezoidal fuzzy neutrosophic number. The proposed algorithm gives the shortest path length using signed distance from source node to destination node. Finally, an illustrative example is provided to show the applicability and effectiveness of the proposed approach.

***Keywords* :** *shortest path, weighted graph, Trapezoidal fuzzy neutrosophic number, Bellman dynamic programming.*

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1. INTRODUCTION

A neutrosophic set proposed by Smarandache is a powerful mathematical tool for dealing with incomplete, indeterminate and inconsistent information cannot be dealt with fuzzy sets as well as intuitionistic fuzzy sets in real world. The concept of neutrosophic set is characterized by three independent membership degrees namely truth membership degree (T), indeterminacy-membership degree (I), and falsity-membership degree (F), which are within the real standard or nonstandard unit interval] $^-0, 1^+$ [. Therefore, if their range is restrained with the real standard unit interval [0,1], the neutrosophic set is easily applied to engineering problems. For this purpose, samarandache and wang et al. introduced the concept of a single valued neutrosophic set [SVNS] as a subclass of the neutrosophic set.

In this paper attention has been paid to the study of determination of shortest path in an network by applying dynamic programming approach. The main objective of this paper is to determine the shortest path from a source node to a destination in a network where the edge weights are uncertain. Bellman dynamic programming technique is applied to determine the shortest path and where the edge weights are characterized by trapezoidal fuzzy neutrosophic number. For comparison of fuzzy number fuzzy ranking technique has been adopted as discussed by Yao and Wu.

The article is organized as follows. Some basic concepts of neutrosophic sets, single valued neutrosophic set, and trapezoidal fuzzy neutrosophic number are introduced in section 2. In section 3, a network terminology is introduced. Computation of shortest path in fuzzy network with connected edges in neutrosophic data is proposed in section 4. Section 5 illustrates a numerical example which is solved by the proposed method. Conclusion and further research are given in section 6.

2. PRELIMINARIES

In this section, we introduced some basic concepts, definitions; arithmetic operations and signed distance for trapezoidal fuzzy neutrosophic number have been discussed.

Definition 2.1 ***Neutrosophic Set:***

Let X be a space of points (objects) with generic elements in X denoted by X; then the neutrosophic set A (NS A) is an object having the form A= $\{\langle X: T_A(x), I_A(x), F_A(x)\rangle, x \in X\}$, where the function T,I,F : X→ $]^-0, 1^+[$ define respectively the truth-membership function , the indeterminacy-membership and the falsity-membership function of the element x$\in X$ to set A with the condition:

$$^-0 \leq T_A(x) + I_A(x) + F_A(x) \leq 3^+$$

The function $T_A(x),\ I_A(x), and\ F_A(x)$ are real standard or non-standard subset of $]^-0, 1^+[$. Since it is difficult to apply NSs to practical problems, Wang et al introduced the concept of a SVNS, which is an instance of neutrosophic set and can be utilized in real scientific and engineering applications.

Definition 2.2 ***Single Valued Neutrosophic Set***

Let X be an universe of discourse of points (objects) with generic elements in X denoted by x. A single valued neutrosophic set A is characterized by truth-membership function$T_A(x)$, an indeterminacy-membership function $I_A(x)$, and a falsity-membership$F_A(x)$. For each point x in X.

$T_A(x), I_A(x), F_A(x) \in [0,1]$

A single valued neutrosophic set can be written as

$A = \{\langle x; T_A(x),\ I_A(x), F_A(x)\rangle, x \in X\} \quad \forall\, x \in X$

$0 \leq T_A(x) +\ I_A(x) + F_A(x) \leq 3$

Definition 2.3 ***Trapezoidal Fuzzy Neutrosophic Set (TrFNS)***

Assume that X be a finite universe of discourse and F[0,1] be the set of all trapezoidal fuzzy numbers on [0,1]. A trapezoidal fuzzy neutrosophic set (TrFNS)

$\tilde{A} = \langle x: \widetilde{T_A}(x), \widetilde{I_A}(x), \widetilde{F_A}(x)\rangle, x \in X$

Where,

$\widetilde{T_A}(x): X \rightarrow F[0,1]$

$\widetilde{I_A}(x): X \rightarrow F[0,1]$

$\widetilde{F_A}(x): X \rightarrow F[0,1]$

The trapezoidal fuzzy numbers

$\widetilde{T_A}(x) = \{T_A^1(x), T_A^2(x), T_A^3(x), T_A^4(x)\}$

$\widetilde{I_A}(x) = \{I_A^1(x), I_A^2(x), I_A^3(x), I_A^4(x)\}$

$\widetilde{F_A}(x) = \{F_A^1(x), F_A^2(x), F_A^3(x), F_A^4(x)\}$ respectively denote the truth-membership, indeterminacy-membership and falsity-membership degree of x in $\tilde{A}$ and for every x$\in X$

$0 \leq T_A^4(x) + I_A^4(x) + F_A^4(x) \leq 3$

Notations:- Trapezoidal fuzzy neutrosophic value (TrFNV)

For notational convenience, the trapezoidal fuzzy neutrosophic value (TrFNV) $\widetilde{A}$ is denoted by

$\tilde{A} = \langle (a_1, a_2, a_3, a_4), (b_1, b_2, b_3, b_4), (c_1, c_2, c_3, c_4)\rangle$

Where, $(T_A^1(x), T_A^2(x), T_A^3(x), T_A^4(x)) = (a_1, a_2, a_3, a_4)$

$(I_A^1(x), I_A^2(x), I_A^3(x), I_A^4(x)) = (b_1, b_2, b_3, b_4)$ and

$(F_A^1(x), F_A^2(x), F_A^3(x), F_A^4(x)) = (c_1, c_2, c_3, c_4)$

The parameters satisfy the following relations

$a_1 \leq a_2 \leq a_3 \leq a_4, b_1 \leq b_2 \leq b_3 \leq b_4, and\ c_1 \leq c_2 \leq c_3 \leq c_4$

Definition 2.4 ***Zero Trapezoidal fuzzy neutrosophic Number***

A trapezoidal fuzzy neutrosophic number $\tilde{A} = \langle(a_1, a_2, a_3, a_4), (b_1, b_2, b_3, b_4), (c_1, c_2, c_3, c_4)\rangle$ is said to be zero trapezoidal fuzzy neutrosophic number iff

$(a_1, a_2, a_3, a_4) = (0,0,0,0)$
$(b_1, b_2, b_3, b_4) = (1,1,1,1)$
$(c_1, c_2, c_3, c_4) = (1,1,1,1)$

Definition 2.5 ***Trapezoidal Fuzzy Neutrosophic Number (TFNN)***

A trapezoidal fuzzy neutrosophic number A is given by A= $(\langle p, q, r, s\rangle, \langle l, m, n, o\rangle\langle w, x, y, z\rangle)$ are the membership,indeterminacy and non membership numbers of A.

The addition of two trapezoidal fuzzy neutrosophic numbers is as follows:

For two trapezoidal fuzzy neutrosophic numbers

A = $(\langle a_1, b_1, c_1, d_1: T_A\rangle, \langle e_1, f_1, g_1, h_1: I_A\rangle, \langle i_1, j_1, k_1, l_1: F_A\rangle)$

B = $(\langle a_2, b_2, c_2, d_2: T_B\rangle, \langle e_2, f_2, g_2, h_2: I_B\rangle, \langle i_2, j_2, k_2, l_2: F_B\rangle)$

With $T_A \neq T_B;\ I_A \neq I_B \text{ and } F_A \neq F_B$

Define A+B

$$A+B = \begin{cases} \langle a_1 + a_2, b_1 + b_2, c_1 + c_2, d_1 + d_2\rangle: Min\ (T_A, T_B) \\ \langle e_1 + e_2, f_1 + f_2, g_1 + g_2, h_1 + h_2\rangle: Min\ (I_A, I_B) \\ \langle i_1 + i_2, j_1 + j_2, k_1 + k_2, l_1 + l_2\rangle: Max\ (F_A, F_B) \end{cases}$$

Definition 2.6 ***Signed Distances***

For each $\tilde{d} = (\langle a, b, c, d\rangle, \langle e, f, g, h\rangle, \langle i, j, k, l\rangle) \in F$, the signed distance of $\tilde{d}$ measured from 0 is defined by d $(\tilde{d}, 0) = \frac{1}{4}[(a + e + i), (b + f + j), (c + g + k), (d + \mathrm{h} + l]$.

From the definition of each

$$\tilde{d} = [(\langle a_1, a_2, a_3, a_4\rangle, \langle a_5, a_6, a_7, a_8\rangle\langle a_9, a_{10}, a_{11}, a_{12}\rangle), (\langle b_1, b_2, b_3, b_4\rangle, \langle b_5, b_6, b_7, b_8\rangle, \langle b_9, b_{10}, b_{11}, b_{12}\rangle), (\langle c_1, c_2, c_3, c_4\rangle\langle c_5, c_6, c_7, c_8\rangle\langle c_9, c_{10}, c_{11}, c_{12}\rangle)]$$

$$= \frac{1}{4}[\langle a_1 + a_5 + a_9, a_2 + a_6 + a_{10}, a_3 + a_7 + a_{11}, a_4 + a_8 + a_{12}\rangle, 2\langle b_1 + b_5 + b_9, b_2 + b_6 + b_{10}, b_3 + b_7 + b_{11}, b_4 + b_8 + b_{12}\rangle, \langle c_1 + c_5 + c_9, c_2 + c_6 + c_{10}, c_3 + c_7 + c_{11}, c_4 + c_8 + c_{12}\rangle]$$

3. FORMULATION FOR SHORTEST PATH LENGTH PROCEDURE IN NEUTROSOPHIC SENSE USING BELLMAN DYNAMIC PROGRAMMING

According to Bellman's equation, a dynamic programming formulation for the shortest path problem can be given as follows:

Given a network with an acyclic directed graph G = (V, E) with n vertices numbered from 1 to n such that 1 is the source and n is the destination.

Then we have

$f(n) = 0$

$$f(i) = \min_{i<j}\{d_{ij} + f(i)/\langle i, j\rangle \in E\} \quad (1)$$

Here d_{ij} is the weight of the directed edge$\langle i, j\rangle$, and $f(i)$ is the length of the shortest path from vertex i to vertex n.

From the following figure the solution of dynamic programming can be derived as follows:

ILLUSTRATIVE EXAMPLE

Consider a network with trapezoidal fuzzy neutrosophic arc length as shown below.

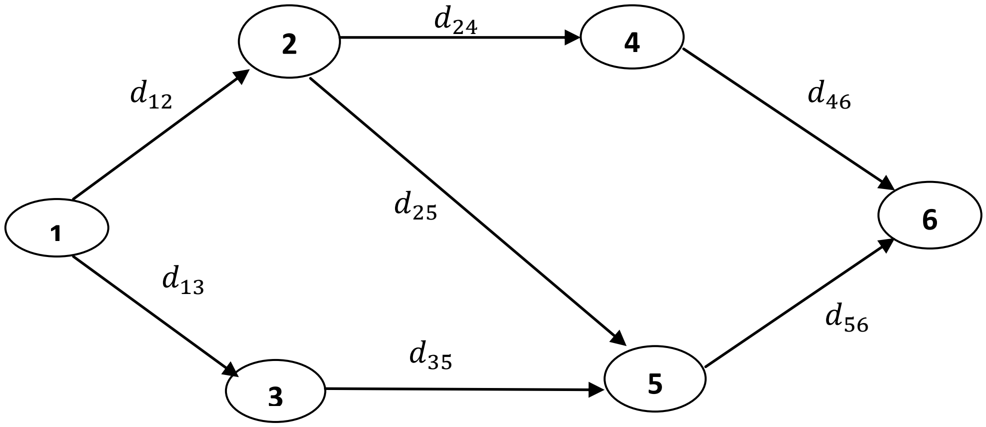

Figure 1. The Distance Network

The arc length are assumed to be;

$d_{12} = (\langle 12, 22, 27, 31\rangle, \langle 25, 30, 42, 50\rangle, \langle 26, 32, 47, 56\rangle)$
$d_{13} = (\langle 20, 25, 30, 41\rangle, \langle 24, 28, 32, 49\rangle, \langle 40, 52, 60, 66\rangle)$
$d_{24} = (\langle 13, 17, 28, 42\rangle, \langle 17, 23, 35, 50\rangle, \langle 25, 37, 44, 58\rangle)$
$d_{25} = (\langle 27, 39, 42, 51\rangle, \langle 35, 44, 52, 59\rangle, \langle 39, 40, 51, 63\rangle)$
$d_{35} = (\langle 15, 17, 24, 32\rangle, \langle 20, 31, 44, 56\rangle, \langle 29, 32, 42, 59\rangle)$
$d_{46} = (\langle 24, 29, 35, 37\rangle, \langle 29, 30, 36, 51\rangle, \langle 30, 32, 49, 55\rangle)$
$d_{56} = (\langle 23, 28, 37, 41\rangle, \langle 26, 32, 42, 49\rangle, \langle 30, 35, 45, 52\rangle)$

The possible paths are as follows:

$d_1 : 1-2-4-6 \quad L_1 = (\langle 49, 68, 90, 110\rangle, \langle 71, 83, 113, 151\rangle, \langle 81, 101, 140, 169\rangle)$
$d_2 : 1-2-5-6 \quad L_2 = (\langle 62, 89, 106, 123\rangle, \langle 86, 106, 136, 158\rangle, \langle 95, 107, 143, 171\rangle)$
$d_3 : 1-3-5-6 \quad L_3 = (\langle 58, 70, 91, 114\rangle, \langle 70, 91, 118, 154\rangle, \langle 99, 119, 147, 177\rangle)$

From figure (1) and equation (1), the solution of dynamic Programming can be derived as follows:

$f(6) = 0$
$f(5) = \min_{5<j}\{d_{5j} + f(j) / \langle 5, j\rangle \in E\} = d_{56} = (\langle 23,28,37,41\rangle, \langle 26,32,42,49\rangle, \langle 30,35,45,52\rangle)$
$f(4) = \min_{4<j}\{d_{4j} + f(j) / \langle 4, j\rangle \in E\} = d_{46} = (\langle 24,29,35,37\rangle, \langle 29,30,36,51\rangle, \langle 30,32,49,55\rangle)$
$f(3) = \min_{3<j}\{d_{3j} + f(j) / \langle 3, j\rangle \in E\} = d_{35} + d_{56}$
$= (\langle 15,17,24,32\rangle, \langle 20,31,44,56\rangle, \langle 29,32,42,59\rangle + \langle 23,28,37,41\rangle, \langle 26,32,42,49\rangle, \langle 30,35,45,52\rangle)$
$f(2) = \min_{2<j}\{d_{2j} + f(j) / \langle 2, j\rangle \in E\} = \min\{(d_{24} + d_{46}), (d_{25} + d_{56})\}$

$f(2) = \min(\langle 13,17,28,42\rangle, \langle 17,23,35,50\rangle, \langle 25,37,44,58\rangle +$
$\langle 24,29,35,37\rangle, \langle 29,30,36,51\rangle, \langle 30,32,49,55\rangle),$
$(\langle 27,39,42,51\rangle, \langle 35,44,52,59\rangle, \langle 39,40,51,63\rangle +$
$\langle 23,28,37,41\rangle, \langle 26,32,42,49\rangle, \langle 30,35,45,52\rangle)\}$
$= \min\{(\langle 37,46,63,79\rangle, \langle 46,53,71,101\rangle, \langle 55,69,93,113\rangle), (\langle 50,67,79,92\rangle, \langle 61,76,94,108\rangle, \langle 69,75,96,115\rangle\}$
$= (\langle 37,46,63,79\rangle, \langle 46,53,71,101\rangle \langle 55,69,93,113\rangle)$
$f(1) = \min_{1<j}\{d_{1j} + f(j) / \langle 1, j\rangle \in E\} = \min d_{12} + d_{24} + d_{46}, d_{12} + d_{25} + d_{56}, d_{13} + d_{35} + d_{56}\}$
$= \min\{d_{12} + f(2), d_{12} + d_{25} + f(5), d_{13} + f(3)\}$
$= \min\{ \langle 49,68,90,110\rangle, \langle 71,83,113,151\rangle, \langle 81,101,140,169\rangle$
$\langle 62,89,106,123\rangle, \langle 86,106,136,158\rangle, \langle 95,107,143,171\rangle,$
$\langle 58,70,91,114\rangle, \langle 70,91,118,154\rangle, \langle 99,119,147,177\rangle\}$
$f(1) = \langle 49,68,90,110\rangle, \langle 71,83,113,151\rangle, \langle 81,101,140,169\rangle$

COMPUTATION OF THE SHORTEST PATH

In this problem we consider is that the edge weight in the network denoted by d_{ij} and the edge weight should be expressed using fuzzy linguistics, and also this used in trapezoidal fuzzy neutrosophic number.

$\widetilde{d_{ij}}= (d_{ij} - \delta_{ij1}, d_{ij}, d_{ij} + \delta_{ij2},),$

Where, $0 < \delta_{ij1} < d_{ij}, \delta_{ij2} > 0$ since δ_{ij1} *and* δ_{ij2} should be determined by the decision maker

From the above definition of signed distance, we obtain

$$d(\widetilde{d_{ij}}.0) = d_{ij} + \frac{1}{4}\delta_{ij} = d°_{ij} \quad (2)$$

where $\delta_{ij} = \delta_{ij3} - \delta_{ij2} - \delta_{ij1}$. This is the signed distance of $\widetilde{d_{ij}}$ measured from 0

Since, $d°_{ij} = d(\widetilde{d_{ij}}.0) = \frac{1}{4}$[4d_ij+δ_ij3-δ_ij2-δ_ij1] $= d_{ij} + \frac{1}{4}(\delta_{ij3} - \delta_{ij2} - \delta_{ij1}) > 0,$

We conclude that $d(\widetilde{d_{ij}},0)$ is a positive distance measured from 0 to $\widetilde{d_{ij}}$ and $d°_{ij}$ is also a positive number measured from 0. If $\delta_{ij1} = \delta_{ij2}$ then we obtain $d°_{ij} = d_{ij}$.

Thus the intuitionistic fuzzy problem becomes crisp. We call $d°_{ij} = d_{ij} + \frac{1}{4}\delta_{ij}$ an estimate of the edge weight $\langle i,j\rangle$ in the intuitionistic fuzzy sense.

We rewrite equation (1) as follows;

For any fixed i ,$f(i) \le d_{ij} + f(j), \forall i < j, \langle i,j\rangle \in E,$

Where at least one equal sign holds. Then

$$d_{ii_1} + d_{i_1i_2} + \cdots + d_{i_mi^n} \le d_{i_j} + d_{jj_1} + d_{j_1j_2} + \cdots + d_{j_mj^n}, \forall i < j, \langle i,j\rangle \in E \quad (3)$$

Where at least one equal sign holds. The decision maker should choose appropriate values for parameters to satisfy

$$\delta_{ii_1} + \delta_{i_1i_2} + \cdots + \delta_{i_mi^n} \le \delta_{i_j} + \delta_{jj_1} + \delta_{j_1j_2} + \cdots + \delta_{j_mj^n}, \forall i < j, \langle i,j\rangle \in E \quad (4)$$

Now consider the intuitionistic fuzzy case. We look for inequalities that satisfy equation (3)

When i=1

$d_{12} + f(2) < d_{13} + f(3) < d_{12} + d_{25} + f(5)$

$d_{12} + d_{24} + d_{46} < d_{13} + d_{35} + d_{56} < d_{12} + d_{25} + d_{56}$

When i = 2 $d_{24} + f(4) < d_{25} + f(5)$ $d_{24} + d_{46} < d_{25} + d_{56}$

Then the parameter of equation (4) based on the above inequalities are derived as

$\delta_{12} + \delta_{24} + \delta_{46} < \delta_{13} + \delta_{35} + \delta_{56} < \delta_{12} + \delta_{25} + \delta_{56}, \quad \delta_{24} + \delta_{46} < \delta_{25} + \delta_{56}$ (5)

If the decision maker choose the values of parameter,

$\delta_{12} = (\langle 2,3,5,7\rangle, \langle 3,5,6,8\rangle, \langle 4,6,7,10\rangle)$ $\delta_{13} = (\langle 3,4,5,7\rangle, \langle 6,7,10,11\rangle, \langle 7,8,11,12\rangle)$

$\delta_{24} = (\langle 3,7,9,11\rangle, \langle 5,8,11,12\rangle, \langle 8,10,12,14\rangle)$ $\delta_{25} = (\langle 1,3,4,6\rangle, \langle 4,7,6,7\rangle, \langle 7,8,11,12\rangle)$

$\delta_{35} = (\langle 5,6,8,10\rangle, \langle 6,9,10,11\rangle, \langle 7,10,12,13\rangle)$ $\delta_{46} = (\langle 2,3,4,6\rangle, \langle 4,5,6,9\rangle, \langle 5,7,9,11\rangle)$

$\delta_{56} = (\langle 1,3,5,7\rangle, \langle 3,5,7,9\rangle, \langle 4,6,9,12\rangle)$

To satisfy the condition in equation (5)then the neutrosophic number can be determined as follows:

$\widetilde{d_{12}} = (\langle 9,18,21,23\rangle, \langle 21,24,35,41\rangle, \langle 21,25,39,45\rangle$
$\langle 12,22,27,31\rangle, \langle 25,30,42,50\rangle, \langle 26,32,47,56\rangle,, \langle 17,29,38,46\rangle, \langle 35,41,55,67\rangle, \langle 35,45,62,77\rangle)$

$\widetilde{d_{13}} = (\langle 16,20,24,33\rangle, \langle 17,20,21,37\rangle, \langle 32,43,48,53\rangle,$
$\langle 20,25,30,41\rangle, \langle 24,28,32,49\rangle, \langle 40,52,60,66\rangle, \langle 27,33,41,56\rangle, \langle 37,43,53,72\rangle, \langle 55,69,82,90\rangle$

$\widetilde{d_{24}} = (\langle 9,9,38,31\rangle, \langle 11,14,23,37\rangle, \langle 16,26,31,43\rangle,$
$\langle 13,17,28,42\rangle, \langle 17,23,35,50\rangle, \langle 25,37,44,58\rangle, \langle 20,25,52,63\rangle, \langle 28,40,55,75\rangle, \langle 42,58,69,87\rangle)$

$\widetilde{d_{25}} = (\langle 25,35,37,44\rangle, \langle 30,36,45,51\rangle, \langle 31,32,39,50\rangle,$
$\langle 27,39,42,51\rangle, \langle 35,44,52,59\rangle, \langle 39,40,51,63\rangle, \langle 30,46,51,64\rangle, \langle 44,59,65,74\rangle, \langle 54,57,74,88\rangle)$

$\widetilde{d_{35}} = (\langle 9,10,15,21\rangle, \langle 13,21,33,44\rangle, \langle 21,21,29,45\rangle,$
$\langle 15,17,24,32\rangle, \langle 20,31,44,56\rangle, \langle 29,32,42,59\rangle, \langle 26,30,41,53\rangle, \langle 33,50,65,79\rangle, \langle 44,53,67,86\rangle)$

$\widetilde{d_{46}} = (\langle 21,25,30,30\rangle, \langle 24,25,29,41\rangle, \langle 24,24,39,43\rangle,$
$\langle 24,29,35,37\rangle, \langle 29,30,36,51\rangle, \langle 30,32,49,55\rangle, \langle 29,36,44,50\rangle, \langle 38,41,479,70\rangle, \langle 41,47,68,67\rangle)$
$\widetilde{d_{56}} = (\langle 21,24,31,30\rangle, \langle 24,25,29,41\rangle, \langle 24,24,39,43\rangle,$
$\langle 24,29,35,37\rangle, \langle 29,30,36,51\rangle, \langle 30,32,49,55\rangle, \langle 29,36,44,50\rangle, \langle 38,41,49,70\rangle, \langle 41,47,68,67\rangle)$

From the definition of signed distance we obtain the following estimate of the edge weight in the neutrosophic sense

$d^\circ{}_{12} = \langle 63.25,85.25,117,138.75\rangle$ $d^\circ{}_{13} = \langle 85.5,106.5,124,157.75\rangle$
$d^\circ{}_{24} = \langle 57.75,78.75,108.25,151.75\rangle$ $d^\circ{}_{25} = \langle 104,124.75,149.25,177\rangle$
$d^\circ{}_{35} = \langle 65,81.5,112,138.75\rangle$ $d^\circ{}_{46} = \langle 84.25,93,122.75,145.25\rangle$
$d^\circ{}_{56} = \langle 80.25,96.25,126,144.75\rangle$

The fuzzy network $G =< V, E >$ with $\{d^\circ{}_{ij} / < i, j > \in E\}$

Where, $f^\circ(1) = d^\circ{}_{12} + f(2) \quad = d^\circ{}_{12} + d^\circ{}_{24} + f(4) \quad = d^\circ{}_{12} + d^\circ{}_{24} + d^\circ{}_{46}$

The fuzzy shortest path is 1-2-4-6 with the length $\langle 205.25,257,348,435.75\rangle$

5. CONCLUSION

In this paper, an algorithm has been developed for solving shortest path problem on a network where the edges are characterized by trapezoidal fuzzy neutrosophic number. Finally a numerical example has been solved to check the efficiency of the proposed method. In future, we will research the application of this algorithm.

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