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On Fuzzy Dominator Chromatic Number Of Middle, Subdivision And Total Fuzzy Soft Graphs

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Abstract— A Fuzzy Soft Dominator Colouring of a fuzzy soft graph $G^S(T,V)$ is an appropriate fuzzy soft colouring such that every single vertex of $G^S(T,V)$ dominate entire vertex of a colour group. In this paper, we initiate fuzzy soft dominator colouring on middle, subdivision and total fuzzy soft graphs of fuzzy soft path and fuzzy soft cycle and its fuzzy dominator chromatic numbers are determined.
Keywords—— fuzzy dominator chromatic number, middle fuzzy soft graph, total fuzzy soft graph, fuzzy soft cycle, fuzzy soft path, strong edges.

1. INTRODUCTION

Rosenfeld described fuzzy analogue of some graph theoretical notions in 1975. Fuzzy set was introduced by Zadeh [19] whose vital component is only a membership function. The overview of Zadeh's fuzzy set, called soft set was proposed by Molodtsov [14] in 1999, to solve unclear problems from the view point of parameters. Maji, P.K., Roy, A.R., Biswas.R.[13] started the idea of fuzzy soft sets which is a combination of fuzzy set and soft set and presented some applications of this concept to decision making problems. In 2016, Akram and Nawaz [16] orginate the notations of fuzzy soft graphs. Akram and Zafar [17] put forward the notions of fuzzy soft cycles, fuzzy soft bridge, fuzzy soft cut node, fuzzy soft trees, and investigate some of their fundamental properties. They also studied some types of arcs in fuzzy soft graphs.
In 2007, R.Gera [8] talk about the problem of Dominator coloring in Graphs and he found bounds and characterizations of several classes of graphs. M.Chellalai and F.Maffray[4] discussed about Dominator Colouring in some classes of Graphs. In 2015, R.Jahir Hussain and K.S.Kanzul [10] came out with the idea on Fuzzy Dominator Colouring in Fuzzy Graphs and found fuzzy dominator chromatic number for different fuzzy graphs and also examined the bounds for the same. R.Jahir Hussain and S.Satham Hussain [12] studied Domination in Fuzzy soft graphs in 2017.
Let $G^S(T,V)$ be a fuzzy soft graph. Let x and y be two nodes of $G^S(T,V)$. We say that vertex x dominates y if (x,y) is a strong arc. A subset D of V is called a dominating set of $G^S(T,V)$ if for every y ∈V-D, there exists x∈D such that x dominates y. A dominating set D in $G^S(T,V)$

is called a minimal dominating set if no proper subset of D is a dominating set. The minimum number of nodes in any dominating set D of $G^S(T,V)$ is called its domination number and is denoted by $\gamma^e(G^S(T,V))$. A Fuzzy Soft Dominator Colouring of a fuzzy soft graph $G^S(T,V)$ is an appropriate fuzzy soft colouring such that every single vertex of $G^S(T,V)$ dominate entire vertex of a colour group. This paper addresses the study of fuzzy Dominator Chromatic Number of Middle, Subdivision and Total Fuzzy Soft Graphs.

2. DEFINITIONS

A. Definition 1:

Let $V = \{ x_1, x_2, x_3, \ldots x_n\}$ is a non – empty set, R is a parameter set and $T \subseteq R$. Also let,

(i) $\alpha: T \rightarrow F(V)$ (set of all fuzzy subsets in V)
$e \dashv \alpha(e) = \alpha_e$ (say)
$\alpha_e: V \rightarrow [0,1]$
(T,α) : Fuzzy Soft vertex

(ii) $\beta: T \rightarrow F(VxV)$ (set of all fuzzy subsets in VxV)
$e \dashv \beta(e) = \beta_e$ (say)
$\beta_e: VxV \rightarrow [0,1]$
(T,β) : Fuzzy Soft egde

Then $((T,\alpha), (T,\beta))$ is called fuzzy soft graph if and only if $\beta_e(x,y) \leq \alpha_e(x) \wedge \alpha_e(y)$ for all $e \in T$ and this fuzzy soft graphs are symbolized by $G^S(T,V)$.

B. Definition 2:

The underlying crisp graph of a fuzzy soft graph $G^S(T,V) = ((T,\alpha), (T,\beta))$ is denoted by $G^{S*}(T,V) = (\alpha^*,\beta^*)$ where $\alpha^* = \{x \in V: \alpha_e(x) > 0\}$ for some $e \in T$, $\beta^* = \{x \in VxV: \beta_e(x,y) > 0\}$, for some $e \in T$.

C. Definition 3:

A Path of length 'n' in a fuzzy soft graph is a series of distinctive points $x_1, x_2, \ldots, x_n$ such that $\forall e \in T$ and $\beta_e(x_{i-1},xi) > 0$, $\forall i = 1, 2, 3, \ldots, n$.

D. Definition 4:

A fuzzy soft graph $G^S(T,V) = ((T,\alpha), (T,\beta))$ is called fuzzy soft cycle if it contain above one lowest arc.

II. FUZZY SOFT DOMINATOR COLOURING ON FUZZY SOFT GRAPHS

A. Definition 5:

The strength of connectedness in a fuzzy soft graph $G^S(T,V) = ((T,\alpha), (T,\beta))$ between x and y is defined as the maximum strength of all paths between x and y and is denoted by $\beta_e^{\infty}(x,y)$, $e \in T$.

B. Definition 6:

An arc (x,y) in fuzzy soft graph $G^S(T,V) = ((T,\alpha), (T,\beta)$ is said to be strong arc iff $\beta_e(x,y) = \beta_e^{\infty}(x,y)$, $e \in T$ and x, y is said to be strong adjacent vertices (or) efficiently adjoining points.

C. Definition 7:

Two nodes of fuzzy soft graph $G^S(T,V) = ((T,\alpha), (T,\beta))$ are said to be fuzzy independent if, they belong to the same colour group, means there is no strong arc between the two nodes.

D. Definition 8:

A k – fuzzy soft vertex colouring of a fuzzy soft graph $G^S(T,V) = ((T,\alpha), (T,\beta))$ is an allotment of k – colours, commonly mean as 1,2,…,k to the vertices of $G^S(T,V)$. A fuzzy soft vertex colouring is stated as proper colouring if two strong adjacent vertices receive distinct colours.

E. Definition 9:

A fuzzy soft dominator colouring of a fuzzy soft graph $G^S(T,V) = ((T,\alpha), (T,\beta))$ is an appropriate fuzzy soft colouring such that every single vertex of $G^S(T,V)$ dominate entire vertex of a colour group.

F. Definition 10:

Fuzzy dominator chromatic number of a fuzzy soft graph $G^S(T,V) = ((T,\alpha), (T,\beta))$ is the least number of colour groups in a fuzzy soft dominator colouring of $G^S(T,V)$ and it is denoted by $\chi_{fd}^e(G^S(T,V))$, $e \in T$.

3. FUZZY DOMINATOR CHROMATIC NUMBER OF MIDDLE FUZZY SOFT GRAPHS

G. Definition 11:

Let $G^S(T,V) = ((T,\alpha), (T,\beta))$ be a fuzzy soft graph with the underlying crisp graph $G^{S*} = (\alpha^*,\beta^*)$. Let $G^{S*}= (V, E)$. The points and lines of $G^S(T,V)$ are taken collectively as node set of the pair $M(G^S(T,V)$: $(((T, \alpha^M), (T, \beta^M))$ where

$\alpha_e^M(x) = \alpha_t(x)$, if $x \in V$, $e \in T$
$= \beta_e(x)$, if $x \in E$, $e \in T$
$= 0$, otherwise.
$\beta_e^M(e_i, e_j) = \beta_e(e_i) \wedge \beta_e(e_j)$, if e_i , $e_j \in E$ and are adjacent in G^{S*}, $e \in T$
$= 0$, otherwise.
$\beta_e^M(x_i, x_j) = 0$, if $x_i, x_j \in V$, $e \in T$
$\beta_e^M(x_i, e_j) = \beta_t(e_j)$ if $x_i \in V$ and it lies on the edge $e_j \in E$, $e \in T$
$= 0$, otherwise.

As α_e^M is defined through the values of α_e and β_e such that α_e^M: V U E → [0, 1] is a exact fuzzy subset on V U E. Also β_e^M is a fuzzy relation on α_e^M and $\beta_e(x,y) = \alpha_e(x) \wedge \alpha_e(y)$, for every $x,y \in$ V U E. Hence the combination $M(G^S(T,V)$: $(((T, \alpha^M), (T, \beta^M))$ is a fuzzy soft graph called middle fuzzy soft graph of $G^S(T,V)$.

H. Theorem 1:

If $G^S(T,V)$ be a fuzzy soft cycle of size 'n', then $\chi_{fd}^e(M(G^S(T,V)) = \left\lceil \frac{n}{2} \right\rceil + 2$, $e \in T$.

Proof:
Let $G^S(T,V)$ be a fuzzy soft cycle with 'n' points $x_1, x_2, ..., x_n$ and 'n' lines $e_1, e_2, ..., e_n$.

Establish the middle fuzzy soft graph of $G^S(T,V)$ with the points $x_1, x_2,..., x_n ,e_1, e_2,...,e_n$. Then sketch an arc between 2 points of $M(G^S(T,V))$ either if

(i) The points of $M(G^S(T,V))$ are arcs of $G^S(T,V)$ (or)
(ii) One of the point 'x' in vertex set and another node 'e' in edge set and x lies on e.

(iii) The membership values are assigned to the points and lines by using the definition of middle fuzzy soft graph.

Now colour the points of $M(G^S(T,V))$ in which 2 efficiently adjoining points receive distinct colours and every point of $M(G^S(T,V))$ dominate one colour group. We have 2 cases w.r.t. 'n'.

Case 1: If n is even, allot colour 1 to $x_1, x_2,..., x_n$, colour 2 to $e_2, e_4,..., e_n$ and the colours $3,4,..., \left\lceil\frac{n}{2}\right\rceil + 2$ to $e_1, e_3, .., e_{n-1}$ correspondingly.

Case 2: If n is odd, add colour 1 to $x_1, x_2, .., x_n$, colour 2 to $e_2, e_4, ...,e_{n-3}, e_{n-1}$ and $3,4, ..., \left\lceil\frac{n}{2}\right\rceil+ 2$ correspondingly.

From the above two cases, it is evident that the final colouring is a least fuzzy soft dominator colouring of $M(G^S(T,V))$ because each node in minimum dominating set meet with a unique colour. As a result $\chi_{fd}^e(M(G^S(T,V)) = \left\lceil\frac{n}{2}\right\rceil + 2$, $e \in T$.

I. *Theorem 2:*

If $G^S(T,V)$ be a fuzzy soft path of size 'n', then $\chi_{fd}^e(M(G^S(T,V)) = \begin{cases} n, & if\ n = 2,3 \\ \left\lceil\frac{n}{2}\right\rceil + 2, & if\ n \geq 4 \end{cases}$,$e \in T$.

Proof:

Consider a fuzzy soft path $G^S(T,V)$ having 'n' points and n-1 strong lines.

Set up a middle fuzzy soft graph of $G^S(T,V)$ with 2n-1 points, each point is efficiently adjoin to its neighbouring nodes.

Next we have to give a unique colour to the points of least dominating set to attain the least fuzzy soft dominator colouring.

It is uncomplicated to prove that $\chi_{fd}^e(M(G^S(T,V)) = n$, for n =2,3.

Consider the following cases for $n \geq 4$.

Case 1: $n\equiv0 \pmod 2$

The least dominating set $D = \{e_1, e_3,...,e_{n-1}\}$ in $M(G^S(T,V))$ having $\frac{n}{2}$ elements. The points $x_1, x_2,...x_n$ gain colour 1, $e_2, e_4,...,e_{n-2}$ gain colour 2 and $e_1, e_3,...,e_{n-1}$ are coloured by $3,4,..., \frac{n}{2} + 2$ correspondingly. Hence we get the proper fuzzy soft dominator colouring as $\left\lceil\frac{n}{2}\right\rceil + 2, if\ n \geq 4$.

Case 2: $n\equiv1 \pmod 2$

In this case, the least dominating set D is $\{e_1, e_3,... e_{n-2},e_{n-1}\}$ and it contains $\frac{n}{2}$ elements. The nodes $x_1, x_2,...x_n$ gains colour 1, $e_2, e_4,...,e_{n-3}$ gains colour 2 and $e_1, e_3,...,e_{n-1}$ are coloured by $3,4,..., \frac{n}{2} + 2$ respectively. Hence we obtain the proper fuzzy soft dominator colouring as $\left\lceil\frac{n}{2}\right\rceil + 2, if\ n \geq 4$.

4. FUZZY DOMINATOR CHROMATIC NUMBER OF SUBDIVISION FUZZY SOFT GRAPHS

J. *Definition 12:*

Let $G^S(T,V) = ((T,\alpha), (T,\beta))$ be a fuzzy soft graph with the underlying crisp graph $G^{S*} = (\alpha^*,\beta^*)$. Then the pair $SD(G^S(T,V)$: $(((T, \alpha^{SD}), (T, \beta^{SD}))$ is a subdivision fuzzy soft graph of $G^S(T,V)$, with vertex set V U E where

$\alpha_e^{SD}(x_i) = \alpha_e(x_i)$, $x_i \in V$, $e \in T$
$\alpha_e^{SD}(e_i) = \beta_e(e_i)$, $e_i \in E$, $e \in T$
= 0, otherwise

$\beta_e^{SD}(x_i,e_j) = \alpha_e(x_i) \wedge \alpha_e(e_i)$, if $x_i \in V$, $e_i \in E$, $e \in T$ and x_i lies on e_j
= 0, otherwise.

K. Theorem 3:

If C_n^e be a fuzzy soft cycle of size $n \geq 3$, in that case $\chi_{fd}^e(SD((C_n^e)) = \left\lceil \frac{2n}{3} \right\rceil + 2$, $e \in T$.

Proof:

Consider a fuzzy soft cycle C_n^e of size $n \geq 3$ having 'n' points $x_1, x_2, \ldots, x_n$ and 'n' arcs $e_1, e_2, \ldots, e_n$ which satisfies the condition $\beta_e(ei) = \beta_e^{\infty}(ei)$, $e \in T$.

To obtain the subdivision graph of fuzzy soft cycle, divide every arc in C_n^e and we get 2n points where each arc e_i is efficiently adjoin with x_i and x_{i+1}. In view of the fact that, $(SD((C_n^e))$ contains 2n points and all that points are efficiently adjoin with two of its neighbouring points.

This implies that $(SD((C_n^e))$ is fuzzy soft cycle of size 2n.

"If G is a fuzzy cycle of length n, then $\chi_{fd}(G) = \left\lceil \frac{n}{3} \right\rceil$ for n=4 and $\chi_{fd}(G) = \left\lceil \frac{n}{3} \right\rceil + 2$ for $n \geq 5$". [10]

Hence we have $\chi_{fd}^e(SD((C_n^e)) = \left\lceil \frac{2n}{3} \right\rceil + 2$ for $n \geq 3$, $e \in T$.

L. Theorem 4:

If P_n^e be a fuzzy soft path of size 'n', then

$$\chi_{fd}^e(SD((P_n^e)) = \begin{cases} \left\lceil \frac{2n-1}{3} \right\rceil + 1, if\ n = 3 \\ \left\lceil \frac{2n-1}{3} \right\rceil + 2, if\ n \geq 4 \end{cases}, e \in T.$$

Proof:

Consider a fuzzy soft path P_n^e having 'n' points and n-1 arcs.

Construct the subdivision graph of fuzzy soft path P_n^e by divide each edge & it form a new point which is strong adjacent to its adjacent vertices.

The resulting graph is again a fuzzy soft path of 2n-1 points and 2n strong arcs.

"If G is a fuzzy graph such that G*= (V,E) is a path of length $n \geq 3$ then $\chi_{fd}(G) = 1 + \left\lceil \frac{n}{3} \right\rceil$, for n = 3,4 and 5 and $\chi_{fd}(G) = 2 + \left\lceil \frac{n}{3} \right\rceil$, for $n \geq 6$".[10]

Hence we conclude from the above result that

$$\chi_{fd}^e(SD((P_n^e)) = \begin{cases} \left\lceil \frac{2n-1}{3} \right\rceil + 1, if\ n = 3 \\ \left\lceil \frac{2n-1}{3} \right\rceil + 2, if\ n \geq 4 \end{cases}, e \in T.$$

5. FUZZY DOMINATOR CHROMATIC NUMBER OF TOTAL FUZZY SOFT GRAPHS

M. Definition 13:

Let $G^S(T,V) = ((T,\alpha), (T,\beta))$ be a fuzzy soft graph with the underlying crisp graph $G^{S*} = (\alpha^*, \beta^*)$. The pair $T(G^S(T,V)) = (((T, \alpha^T), (T, \beta^T))$ of $G^S(T,V)$ is described as follows. The vertex set of $T(G^S(T,V))$ be V U E. The fuzzy subset $\alpha_e^T(x)$ is defined on V U E as

$\alpha_e^T(x) = \alpha_e(x)$, $x \in V$, $e \in T$
$= \beta_e(e_i)$, $e_i \in E$, $e \in T$

The fuzzy relation on β_e^T is given as

$\beta_e^T(x_i,x_j) = \beta_e(x_i,x_j)$, if $x_i,x_j \in V$, $e \in T$
$\beta_e^T(e_i,e_j) = \beta_e(e_i) \wedge \beta_e(e_j)$, if e_i, $e_j \in E$ and e_i and e_j have a common node between them.
$\beta_e^T(e_i,e_j) = 0$, otherwise
$\beta_e^T(x_i,e_j)= \alpha_e(x_i) \wedge \beta_e(e_j)$, if $x_i \in V$, $e_i \in E$, $e \in T$ and x_i lies on the edge e_j.
Hence the pair $T(G^S(T,V))$: $(((T, \alpha^T), (T, \beta^T))$ is a total fuzzy soft graph of $G^S(T,V)$.

N. Theorem 5:

If C_n^e be a fuzzy soft cycle of size $n \geq 3$, then $\chi_{fd}^e(T((C_n^e))= \begin{cases} \left\lceil \frac{2n}{5} \right\rceil + 2, if\ n = 3 \\ \left\lceil \frac{2n}{5} \right\rceil + 3, if\ n \geq 4 \end{cases}$, $e \in T$.

Proof:
Consider a fuzzy soft cycle C_n^e, $e \in T$ of size $n \geq 3$ and the points of C_n^e is given as $x_1, x_2, \ldots x_n$ and the lines are denoted by $e_1,e_2,\ldots e_n$ where $e_i= v_iv_{i+1}$, $1\leq i \leq n-1$ and $\beta_t(e_i) = \beta_t^{\infty}(e_i)$.
Construct the total fuzzy soft graph of C_n^e, $e \in T$ such that $T(C_n^e)$ contains 2n points labeled as $v_1,v_2,\ldots v_{2n}$ & two points in $T(C_n^e)$ are adjacent if,

(i) Both points are in V.
(ii) one point v is in V and e is in E and v lies on e.
(iii) Both nodes are in E.
The membership values are assigned to the points and lines with the definition of total fuzzy soft graph.
Now colour the points of $T(C_n^e)$, $e \in T$ with the condition that 2 strong adjacent points receive distinct colours and all the points of C_n^e, $e \in T$ dominate one colour group.
It is obvious to see that, $\chi_{fd}^e(T((C_n^e)) = \left\lceil \frac{2n}{5} \right\rceil + 2, if\ n = 3,$ $e \in T$.
Now we have to prove for the case $n \geq 4$.
Assign the colours (1,2,3,1) to v_{2+5i}, v_{3+5i}, v_{4+5i}, v_{5+5i} if 'i' is even, and if 'i' is odd, give colours (2,3,1,2) to the same points, for $0\leq i \leq \left\lceil \frac{2n-1}{5} \right\rceil$.
The point v_{1+5i}, $0\leq i \leq \left\lceil \frac{2n-1}{5} \right\rceil$ is coloured by (4+i), since the point v_{1+5i} dominates itself and its connecting points v_{1+5i-2}, v_{1+5i-1}, v_{1+5i+1}, v_{1+5i+2} for $0< i \leq \left\lceil \frac{2n-1}{5} \right\rceil$ and if i = 0, then v_2, v_3, v_{2n}, v_{2n-1} dominate the color group 4.

Hence the resulting colouring is a least fuzzy soft dominator colouring of $T(C_n^e)$ because each point in a least dominating set gains a unique colour. Hence $\chi_{fd}^e(T((C_n^e))= \left\lceil \frac{2n}{5} \right\rceil + 3, if\ n \geq 4$, $e \in T$.

O. Theorem 6:

If P_n^e, is a fuzzy soft path of size $n\geq 3$, then
$\chi_{fd}^e(T((P_n^e))= \begin{cases} \left\lceil \frac{2n}{3} \right\rceil + 2, if\ n = 3 \\ \left\lceil \frac{2n}{3} \right\rceil + 1, if\ n \geq 4 \end{cases}$, $e \in T$.
Proof:
Consider a fuzzy soft path P_n^e of 'n' points $v_1,v_2,\ldots v_n$ and n-1 strong arcs $e_1,e_2,\ldots e_{n-1}$.
Establish the total fuzzy soft graph of P_n^e, $e \in T$. $T(P_n^e)$ contains 2n-1 points labeled as $v_1,v_2,\ldots v_{2n-1}$ and 2 points are adjoining if both points are in V (or) both are in E, also $v \in V$, $e \in E$ and v lies on E.
Assign the membership values for vertex set and edge set by the definition of total fuzzy soft graph.

Now colour the points of $T(P_n^e)$, $e \in T$ with the condition that 2 strong adjoining points receive distinct colours and all points of P_n^e, $e \in T$ dominate one colour group.

It is easy to prove that $\chi_{fd}^e(T((P_n^e)) = \left\lceil \frac{2n}{3} \right\rceil + 2$, for n =3, e ∈ T.

The fuzzy soft dominator colouring of $T(P_n^e)$ for n ≥4 is obtained by the following procedure.

Assign colour 1 to v_{1+3j}, colour 2 to v_{2+3j} and colour (3+j) to v_{3+3j}, for $0 \leq j \leq \left\lceil \frac{2n}{3} \right\rceil$.

The point v_{3+3j} dominates itself and its connecting points of colour group (3+j).

Hence the resulting colouring is a least fuzzy soft dominator colouring of $T(P_n^e)$ since each point in a least dominating set gains a unique colour. Hence $\chi_{fd}^e(T((P_n^e)) = \left\lceil \frac{2n}{3} \right\rceil + 1, if\ n \geq 4$, e ∈ T.

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