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Operations on Complex Hesitancy Fuzzy Graph

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Abstract: In this paper, Complex Hesitancy Fuzzy Graph (CHFG) is analyzed and we have discussed new concepts in CHFG such as Complete CHFG with example. Further we defined some operations on Complex Hesitancy Fuzzy Graph such as direct product, semi strong product and strong product. Also fundamental theorems and their apllications will be examined. Additionally, new ideas in the density of a CHFG and balanced complex Hesitancy fuzzy graph have been introduced in this work.
Keywords: Complete Complex Hesitancy Fuzzy Graph, Direct Product of CHFG, Semi Strong Product of CHFG, Strong Product of CHFG, Balanced CHFG and Density of CHFG.

I. INTRODUCTION

Zadeh[19],[20],[21] defined the fuzzy set in 1965, and a membership function with a range of[0,1] is a necessary component. Kalaiarasi and Mahalakshmi[4] provided an Introduction to fuzzy soft graph, fuzzy strong graph and its complement. Some applications of μ-complement fuzzy soft graph and fuzzy strong graph and complement of fuzzy strong graph. They additionally proposed a colouring of regular and strong arcs of fuzzy graph and they also extended the concept of regular and irregular m-polar fuzzy graph.Then, by incorporating non-belongingness and hesitation degrees into the fuzzy set, Atanassov[2]presented the idea of the intuitionistic fuzzy set in 1986.Atanassov added new components that determine the degree of non-membership.

A innovative idea of hesitant fuzzy sets was refined and generalized in 2009 by Torra and Narukawa[15],[16]. According to the HFS concept, each element or object is assigned a set of independent values via the range of membership values. As a result, as compared to Fuzzy Set and Intuitionistic Fuzzy Set, hesitant sets offer more thorough information than the other uncertainty sets. A hesitant fuzzy element was defined in 2011 by Xia and Xu[18]. Hesitancy Fuzzy Set is a successful device to address decisionmakers' (Dm's) reluctant inclinations. It is involved in grouping, enhancement, convexity, navigation, inclination relations, information mining, and conglomeration administrator. Complex hesitancy fuzzy graph has be discussed by AbuHijleh[1].

Qian[7]and Talafha et al[11] worked on complex hesitancy fuzzy sets and decision making. Veeramani and Suresh[17]developed the operations on complex fuzzy graph. For instance, the Hesitancy Fuzzy data could have various meanings for the same object, but they would be based on different factors or phases. Ramot et al[9],[10] developed complex fuzzy sets, Complex intuitionistic fuzzy sets, and complex reluctant fuzzy sets are utilizing two factors to exhibit the full significance of data to beat the hindrances in dynamic in the numerical model. In hesitant fuzzy form, Ccomplex Hesitancy Fuzzy Set uses two sets of variables to represent uncertainty and periodicity semantics. In hesitant fuzzy form, Complex Hesitancy Fuzzy Set uses two sets of variables to represent uncertainty and periodicity semantics. Numerous researchers have discussed a complex fuzzy set extensively. Alkouri and Salleh [3] developed it into a complex intuitionistic fuzzy set in 2012–2013. Talal et al.[12],[13] recently provided a Complex Hesitancy Fuzzy Set-based generalization of Complex Fuzzy Set, Complex Intuitionistic Fuzzy Set, and Hesitancy Fuzzy Set along with its applications in 2021.This paper consists of three major sections. In section 1 Introduction is described. In section 2,preliminaries are discussed. Complex Hesitancy fuzzy graph, characteristic and complete complex hesitancy fuzzy graph and operations on Complex Hesitancy Fuzzy Set such as Direct Product of Complex Hesitancy Fuzzy Set,Semi Strong Product of Complex Hesitancy Fuzzy Set ,Strong Product of Complex Hesitancy Fuzzy Set,Balanced Complex Hesitancy Fuzzy Set and Density of Complex Hesitancy Fuzzy Set have been introduced.Section 4 is the conclusion of this work.

II. PRELIMINARIES

A. Definition 2.1

A fuzzy graph is an ordered triple (G, ρ, χ) where V is the set of vertices $\{u_1, u_2, ..., u_n\}$ and ρ is a fuzzy subset of V that is $\rho : V \to [0,1]$ and is denoted by $\rho = \{(u_1, \rho(u_1)), (u_2, \rho(u_2)), ..., (u_n, \rho(u_n))\}$ and χ is a fuzzy relation on ρ that is $\chi(u, v) \le \rho(u)\rho(v)$.

B. Definition 2.2

Let X be a fixed set.A hesitancy fuzzy set A in X is of the form $A=\{(x,\rho(x),\chi(x),\sigma(x)):x\in X\}$ where $\rho:V\to[0,1]$, $\chi:V\to[0,1]$ and $\sigma:V\to[0,1]$ denote the degree of membership, non membership and hesitancy of the element $x\in X$ respectively and for every $x\in X$, $\rho(x)+\chi(x)+\sigma(x)=1$.

C. Definition 2.3

A Hesitancy Fuzzy Graph is of the form $G:(V,E)$, where $V=\{v_1,v_2,....,v_n\}$ such that $\rho:V\to[0,1]$, $\chi:V\to[0,1]$ and $\sigma:V\to[0,1]$ denote the degree of membership, non membership and hesitancy of the element $v_i\in V$ such that

$i)\rho(v_i)+\chi(v_i)+\sigma(v_i)=1$ and

$ii)\rho(v_i,v_j)\le\min(\rho(v_i),\rho(v_j)),\ \chi(v_i,v_j)\le\max(\chi(v_i),\chi(v_j)),\ \sigma(v_i,v_j)\le\min(\sigma(v_i),\sigma(v_j)),\ v_i,v_j\in V.$

D. Definition 2.4

Let $G_1=(V_1,E_1)$ and $G_2=(V_2,E_2)$ be two graphs. The Direct product of G_1 and G_2 is a graph $G_1\prod G_2=(V,E)$ with $V=V_1\times V_2$ and $E=\{((u_1,v_1),(u_2,v_2))\mid(u_1,u_2)\in E_1,(v_1,v_2)\in E_2\}$ if

i) $(\rho_1\prod\rho_2)(u_1,v_1)=\min(\rho_1(u_1),\rho_2(v_1))$ ii) $(\chi_1\prod\chi_2)(u_1v_1,u_2v_2)=\min(\chi_1(u_1u_2),\chi_2(v_1v_2))$

E. Definition 2.5

Let $G_1=(V_1,E_1)$ and $G_2=(V_2,E_2)$ be two graphs.The Semi strong product of G_1 and G_2 is a graph $G_1*G_2=(V,E)$ with $V=V_1\times V_2$ and $E=\{((u_1,v_1),(u_2,v_2))\mid(u_1,u_2)\in E_1,(v_1,v_2)\in E_2\}$ if,

i) $(\rho_1*\rho_2)(u_1,v_1)=\min(\rho_1(u_1),\rho_2(v_1))$ ii) $(\chi_1*\chi_2)(u_1v_1,u_2v_2)=\min(\chi_1(u_1u_2),\chi_2(v_1v_2))$

F. Definition 2.6

Let $G_1=(V_1,E_1)$ and $G_2=(V_2,E_2)$ be two graphs.The Strong product of G_1 and G_2 is a graph $G_1\otimes G_2=(V,E)$ with $V=V_1\times V_2$ and $E=\{((u_1,v_1),(u_2,v_2))\mid(u_1,u_2)\in E_1,(v_1,v_2)\in E_2\}$ if,

i) $(\rho_1\otimes\rho_2)(u_1,v_1)=\min(\rho_1(u_1),\rho_2(v_1))$ ii) $(\chi_1\otimes\chi_2)(u_1v_1,u_2v_2)=\min(\chi_1(u_1u_2),\chi_2(v_1v_2))$

III. OPERATIONS ON COMPLEX HESITANCY FUZZY GRAPH

A. Definition 3.1

A Complex Hesitancy Fuzzy Graph in the form of $G=(V,\rho,E,\chi)$ where ρ is the set of vertices and χ is the set of edges i.e., $\rho=(\rho_1,\rho_2,\rho_3)$ and $\chi=(\chi_1,\chi_2,\chi_3)$ such that $\rho_1:V\to[0,1]$, $\rho_2:V\to[0,1]$, $\rho_3:V\to[0,1]$ and $\chi_1:V\times V\to[0,1]$, $\chi_2:V\times V\to[0,1]$, $\chi_3:V\times V\to[0,1]$ where ρ_1 and χ_1 are membership function, ρ_2 and χ_2 are non membership function and ρ_3 and χ_3 are the hesitancy of the element if

$0\le\rho_1(u)+\rho_2(v)+\rho_3(w)\le1$ in V and

$i)\chi_1(u,u_1)\le\min\ (\rho_1(u),\rho_1(u_1))$,

$ii)\chi_2(v,v_1)\le\max\ (\rho_2(v),\rho_2(v_1))$,

$iii)\chi_3(w,w_1)\le\min\ (\rho_3(w),\rho_3(w_1))$ u,v,w,u_1,v_1,w_1 in V.

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Example 3.1:

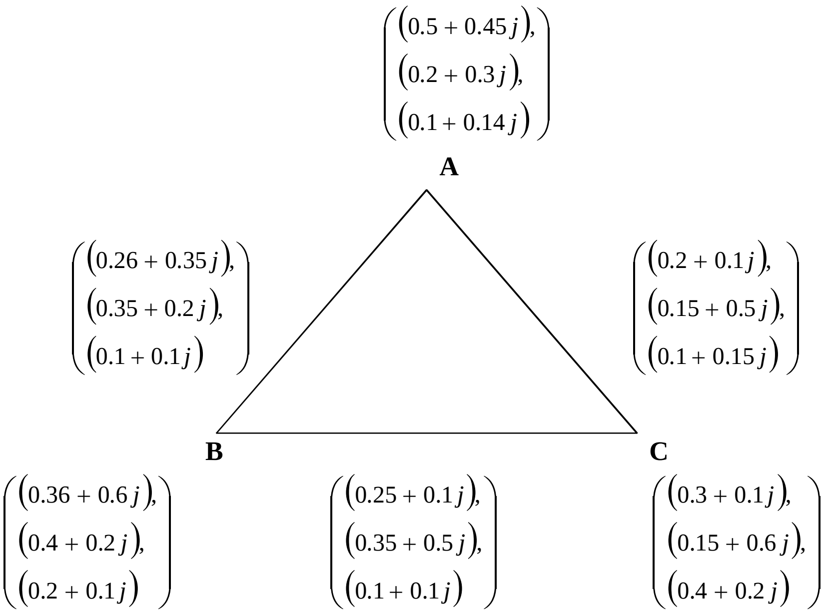

Fig.3.1 Complex Hesitancy Fuzzy Graph

B. *Definition 3.2*

A Complex Hesitancy Fuzzy Graph $G = (V, \rho, E, \chi)$ where ρ is the set of vertices and χ is the set of edges i.e., $\rho = (\rho_1, \rho_2, \rho_3)$ and $\chi = (\chi_1, \chi_2, \chi_3)$suchthat $\rho_1 : V \to [0,1]$, $\rho_2 : V \to [0,1]$, $\rho_3 : V \to [0,1]$and $\chi_1 : V \times V \to [0,1]$ $\chi_2 : V \times V \to [0,1]$, $\chi_3 : V \times V \to [0,1]$ where ρ_1 and χ_1 are membership function, ρ_2 and χ_2 are non membership function and ρ_3 and χ_3 are the hesitancy of the element is said to be complete if

$$i)\left|\chi_1(a,b)\right| = \min\left(\left|\rho_1(a)\right|, \left|\rho_2(b)\right|\right)$$

$$ii)\left|\chi_2(a,b)\right| = \max\left(\left|\rho_2(a)\right|, \left|\rho_2(b)\right|\right)$$

$$iii)\left|\chi_3(a,b)\right| = \min\left(\left|\rho_3(a)\right|, \left|\rho_3(b)\right|\right), \forall a,b \in V$$

Example 3.2

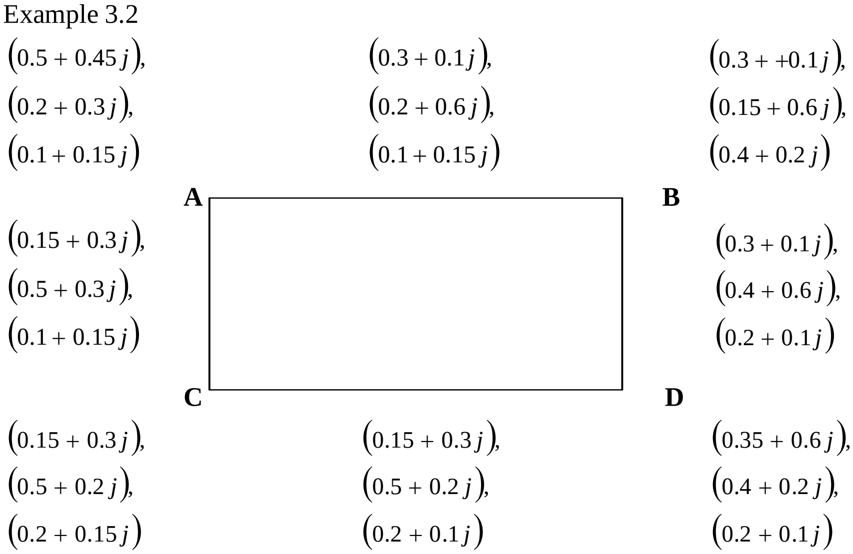

Fig 3.2 Complete Complex Hesitancy Fuzzy Graph

C. Definition 3.3

The Direct product of two Complex Hesitancy Fuzzy Graph is of the form of $G_1 = (V_1, E_1)$ and $G_2 = (V_2, E_2)$ where $(u_1, u_2) \in E_1$ and $(v_1, v_2) \in E_2$, $G_1 : (\rho_1, \chi_1)$ and $G_2 : (\rho_2, \chi_2)$ is defined to be a Complex Hesitancy Fuzzy Graph $G_1 \Pi G_2 : (\rho_1 \Pi \rho_2, \chi_1 \Pi \chi_2)$ where ρ' and χ' denote the degree of the membership function, ρ'' and χ'' denote the degree of the non membership function and ρ''' and χ''' denote the degree of the hesitancy element if

$i)\left(\rho_1' \, \Pi \, \rho_2'\right)(u_1, v_1) = \min\left(\left|\rho_1'(u_1)\right|, \left|\rho_2'(v_1)\right|\right)$

$ii)\left(\rho_1'' \, \Pi \, \rho_2''\right)(u_1, v_1) = \max\left(\left|\rho_1''(u_1)\right|, \left|\rho_2''(v_1)\right|\right)$

$iii)\left(\rho_1''' \, \Pi \, \rho_2'''\right)(u_1, v_1) = \min\left(\left|\rho_1'''(u_1)\right|, \left|\rho_2'''(v_1)\right|\right)$

$iv)\left(\chi_1' \, \Pi \, \chi_2'\right)(u_1, v_1) = \min\left(\left|\rho_1'(u_1)\right|, \left|\rho_2'(v_1)\right|\right)$

$v)\left(\chi_1'' \, \Pi \, \chi_2''\right)(u_1, v_1) = \max\left(\left|\rho_1''(u_1)\right|, \left|\rho_2''(v_1)\right|\right)$

$vi)\left(\chi_1''' \, \Pi \, \chi_2'''\right)(u_1, v_1) = \min\left(\left|\rho_1'''(u_1)\right|, \left|\rho_2'''(v_1)\right|\right)$

D. Definition 3.4

The Semistrong product of two Complex Hesitancy Fuzzy Graph is of the form of $G_1 = (V_1, E_1)$ and $G_2 = (V_2, E_2)$ where $(u_1, u_2) \in E_1$ and $(v_1, v_2) \in E_2$, $G_1 : (\rho_1, \chi_1)$ and $G_2 : (\rho_2, \chi_2)$ is defined to be Complex Hesitancy Fuzzy Graph $G_1 * G_2 : (\rho_1 * \rho_2, \chi_1 * \chi_2)$ where ρ' and χ' denote the degree of the membership function, ρ'' and χ'' denote the degree of the non membership function and ρ''' and χ''' denote the degree of the hesitancy element if

$i)\left(\rho_1' * \rho_2'\right)(u_1, v_1) = \min\left(\left|\rho_1'(u_1)\right|, \left|\rho_2'(v_1)\right|\right)$

$ii)\left(\rho_1'' * \rho_2''\right)(u_1, v_1) = \max\left(\left|\rho_1''(u_1)\right|, \left|\rho_2''(v_1)\right|\right)$

$iii)\left(\rho_1''' * \rho_2'''\right)(u_1, v_1) = \min\left(\left|\rho_1'''(u_1)\right|, \left|\rho_2'''(v_1)\right|\right)$

$iv)\left(\chi_1' * \chi_2'\right)(u_1, v_1) = \min\left(\left|\rho_1'(u_1)\right|, \left|\rho_2'(v_1)\right|\right)$

$v)\left(\chi_1'' * \chi_2''\right)(u_1, v_1) = \max\left(\left|\rho_1''(u_1)\right|, \left|\rho_2''(v_1)\right|\right)$

$vi)\left(\chi_1''' * \chi_2'''\right)(u_1, v_1) = \min\left(\left|\rho_1'''(u_1)\right|, \left|\rho_2'''(v_1)\right|\right)$

E. Definition 3.5

The Strong product of two Complex Hesitancy Fuzzy Graph is of the form of $G_1 = (V_1, E_1)$ and $G_2 = (V_2, E_2)$ where $(u_1, u_2) \in E_1$ and $(v_1, v_2) \in E_2$, $G_1 : (\rho_1, \chi_1)$ and $G_2 : (\rho_2, \chi_2)$ is defined to Complex Hesitancy Fuzzy Graph $G_1 \otimes G_2 : (\rho_1 \otimes \rho_2, \chi_1 \otimes \chi_2)$ where ρ' and χ' denote the degree of the membership function, ρ'' and χ'' denote the degree of the non membership function and ρ''' and χ''' denote the degree of the hesitancy element if

$i)\left(\rho_1' \otimes \rho_2'\right)(u_1, v_1) = \min\left(\left|\rho_1'(u_1)\right|, \left|\rho_2'(v_1)\right|\right)$

$ii)\left(\rho_1'' \otimes \rho_2''\right)(u_1, v_1) = \max\left(\left|\rho_1''(u_1)\right|, \left|\rho_2''(v_1)\right|\right)$

$iii)\left(\rho_1''' \otimes \rho_2'''\right)(u_1, v_1) = \min\left(\left|\rho_1'''(u_1)\right|, \left|\rho_2'''(v_1)\right|\right)$

$iv)\left(\chi_1' \otimes \chi_2'\right)(u_1, v_1) = \min\left(\left|\rho_1'(u_1)\right|, \left|\rho_2'(v_1)\right|\right)$

$v)\left(\chi_1'' \otimes \chi_2''\right)(u_1, v_1) = \max\left(\left|\rho_1''(u_1)\right|, \left|\rho_2''(v_1)\right|\right)$

$vi)\left(\chi_1''' \otimes \chi_2'''\right)(u_1, v_1) = \min\left(\left|\rho_1'''(u_1)\right|, \left|\rho_2'''(v_1)\right|\right)$

F. Definition 3.6

The Density of a complex hesitancy fuzzy graph is $G : (V, E)$ is defined by

$$D_{\chi_1'}(G) = 2\left(\frac{\Sigma_{u_1, v_1 \in V} \left|\chi_1'(u_1, v_1)\right|}{\Sigma_{u_1, v_1 \in V} \min\left(\left|\rho_1'(u_1)\right|, \left|\rho_1'(v_1)\right|\right)}\right)$$

$$D_{\chi_1''}(G) = 2\left(\frac{\sum_{u_1,v_1\in V}\left|\chi_1''(u_1,v_1)\right|}{\sum_{u_1,v_1\in V}\max\left(\left|\rho_1''(u_1)\right|,\left|\rho_1''(v_1)\right|\right)}\right)$$

$$D_{\chi_1'''}(G) = 2\left(\frac{\sum_{u_1,v_1\in V}\left|\chi_1'''(u_1,v_1)\right|}{\sum_{u_1,v_1\in V}\min\left(\left|\rho_1'''(u_1)\right|,\left|\rho_1'''(v_1)\right|\right)}\right)$$

G is balanced if $D(H) \le D(G)$ for all complex hesitancy fuzzy non empty subgraph H of G.

G. *Theorem 3.3*

Direct product of two complete complex hesitancy fuzzy graphs is also a complete complex hesitancy fuzzy graph.

Proof:

Let $G_1 = (\rho_1, \chi_1)$ and $G_2 = (\rho_2, \chi_2)$ be two hesitancy fuzzy graphs.

$$\begin{aligned}
(\chi_1' \Pi \chi_2')(u_1v_1, u_2v_2) &= \min\left(\left|\chi_1'(u_1,u_2)\right|,\left|\chi_2'(v_1,v_2)\right|\right)\\
&= \min\left(\left|\rho_1'(u_1)\right|,\left|\rho_1'(u_2)\right|,\left|\rho_2'(v_1)\right|,\left|\rho_2'(v_2)\right|\right)\\
&= \min\left(\left|\rho_1'(u_1)\right|,\left|\rho_2'(v_1)\right|,\left|\rho_1'(u_2)\right|,\left|\rho_2'(v_2)\right|\right)\\
&= \min\left(\left|\rho_1'(u_1)\right|,\left|\rho_2'(v_1)\right|\right)\min\left(\left|\rho_1'(u_2)\right|,\left|\rho_2'(v_2)\right|\right)\\
&= \min\left(\rho_1' \Pi \rho_2'\right)(u_1,v_1)\min\left(\rho_1' \Pi \rho_2'\right)(u_1,v_2)
\end{aligned}$$

$$(\chi_1' \Pi \chi_2')(u_1v_1, u_2v_2) = \min\left(\rho_1' \Pi \rho_2'\right)(u_1,v_1)\min\left(\rho_1' \Pi \rho_2'\right)(u_1,v_2)$$

$$(\chi_1'' \Pi \chi_2'')(u_1v_1, u_2v_2) = \max\left(\left|\chi_1''(u_1,u_2)\right|,\left|\chi_2''(v_1,v_2)\right|\right)$$

$$(\chi_1'' \Pi \chi_2'')(u_1v_1, u_2v_2) = \max\left(\rho_1'' \Pi \rho_2''\right)(u_1,v_1)\max\left(\rho_1'' \Pi \rho_2''\right)(u_1,v_2)$$

$$(\chi_1''' \Pi \chi_2''')(u_1v_1, u_2v_2) = \min\left(\left|\chi_1'''(u_1,u_2)\right|,\left|\chi_2'''(v_1,v_2)\right|\right)$$

$$(\chi_1''' \Pi \chi_2''')(u_1v_1, u_2v_2) = \min\left(\rho_1''' \Pi \rho_2'''\right)(u_1,v_1)\min\left(\rho_1''' \Pi \rho_2'''\right)(u_1,v_2)$$

Hence $G_1 \Pi G_2$ is a complete complex hesitancy fuzzy graph.

H. *Theorem 3.4*

Semi strong product of two complete complex hesitancy fuzzy graphs is also a complete complex hesitancy fuzzy graph.

I. *Theorem 3.5:*

Strong product of two complete complex hesitancy fuzzy graphs is also a complete complex hesitancy fuzzy graph.

J. *Theorem 3.6:*

Any complete complex hesitancy fuzzy graph is balanced.

Proof: Let G be a complete complex hesitancy fuzzy graph then

$$D_{\chi_1'}(G) = 2\left(\frac{\sum_{u_1,v_1\in V}\left|\chi_1'(u_1,v_1)\right|}{\sum_{u_1,v_1\in V}\min\left(\left|\rho_1'(u_1)\right|,\left|\rho_1'(v_1)\right|\right)}\right)$$

$$D_{\chi_1'}(G) = 2\left(\frac{\Sigma_{u_1,v_1 \in V}\left|\chi_1'(u_1,v_1)\right|}{\Sigma_{u_1,v_1 \in V}\left|\chi_1'(u_1,v_1)\right|}\right)$$

$$D_{\chi_1'}(G) = 2$$

If H is a non empty complex hesitancy fuzzy subgraph of G then

$$D_{\chi_1'}(H) = 2\left(\frac{\Sigma_{u_1,v_1 \in V(H)}\left|\chi_1'(u_1,v_1)\right|}{\Sigma_{u_1,v_1 \in V(H)}\min\left(\left|\rho_1'(u_1)\right|,\left|\rho_1'(v_1)\right|\right)}\right)$$

$$D_{\chi_1'}(H) = 2\left(\frac{\Sigma_{u_1,v_1 \in V(H)}\left|\chi_1'(u_1,v_1)\right|}{\Sigma_{u_1,v_1 \in V(H)}\left|\chi_1'(u_1,v_1)\right|}\right)$$

$$D_{\chi_1'}(H) = 2$$

$$\therefore D_{\chi_1'}(G) = D_{\chi_1'}(H)$$

Similarly,

$$D_{\chi_1''}(G) = D_{\chi_1''}(H)\ ,\quad D_{\chi_1'''}(G) = D_{\chi_1'''}(H)$$

Thus G is balanced.

IV. CONCLUSION

In this paper, we present the Complex Hesitancy Fuzzy Graph. Also, We had derived the Complex Hesitancy Fuzzy Graph with example. Complex Hesitancy Fuzzy Graph(CHFG) emerge as a sophisticated extension of classical graph theory introducing nuanced approach to modeling uncertainty and imprecation through the integration of Complex Hesitancy Fuzzy Sets. Also we derived the concept of Complex Hesitancy Fuzzy Graph(CHFG) and some theorems on complete complex hesitancy fuzzy graph. Then we have applied some operations on CHFG such as Direct Product, Semi strong product and Strong product. Here balanced and density of a CHFG had been discussed. The above complex hesitancy fuzzy graph is useful for real life applications. We are committed to manage other maintainable improvement objectives for a better world.

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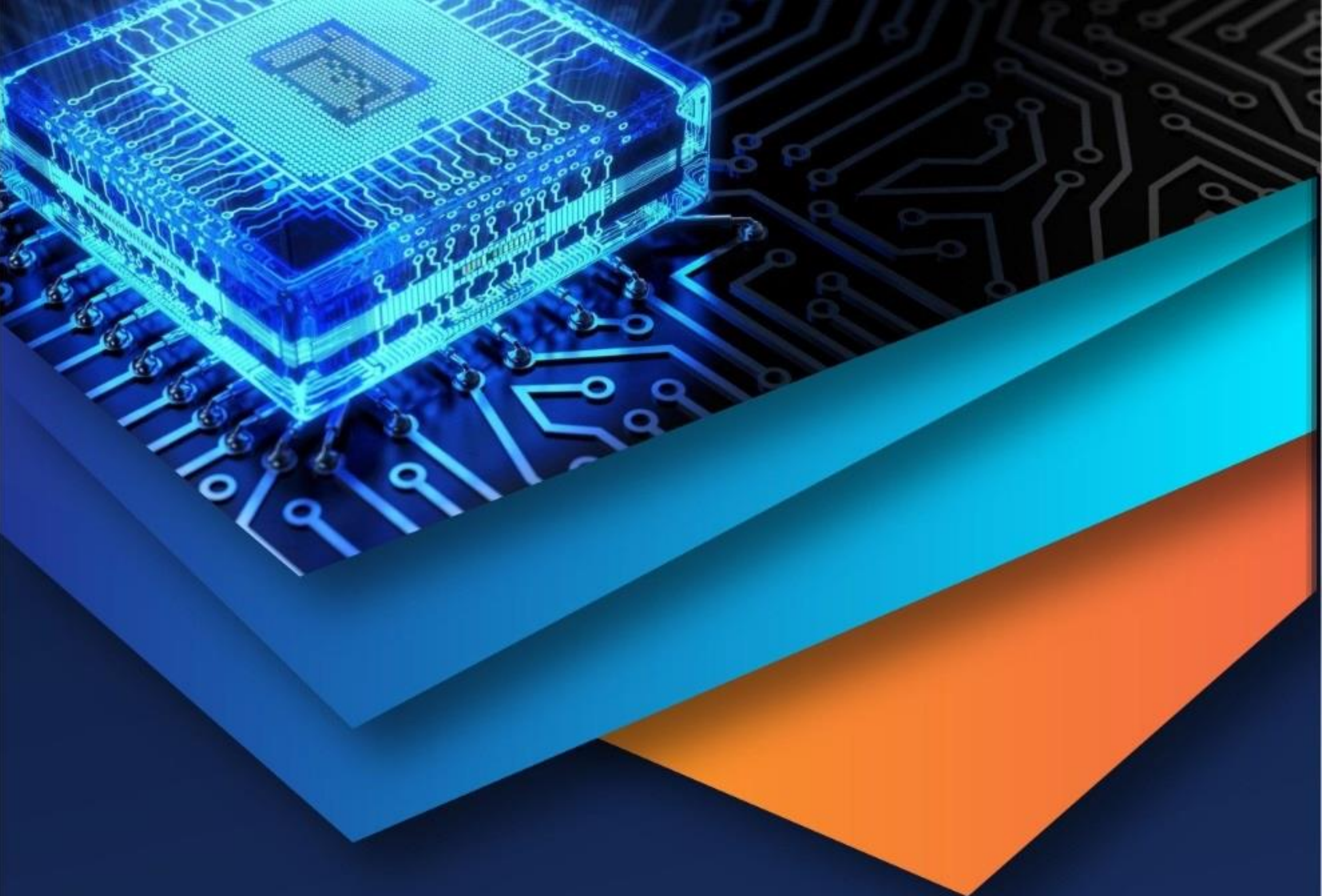

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ISRA JIF IMPACT FACTOR: 7.129

TOGETHER WE REACH THE GOAL IMPACT FACTOR: 7.429

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