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A Study on Constant and Regular Hesitancy Fuzzy Soft Graphs

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Abstract: This article discusses about the degree of vertex, edge in hesitancy fuzzy soft graphs (HFSG). A new kind of graph called constant HFSG and totally constant HFSG are established. The order and size of such graphs are also dealt. The regular and totally regular concepts are introduced over the HFSG, and its properties discussed.

Key Words: Constant HFSG, totally constant HFSG, regular HFSG, size and order, totally regular HFSG, neutrosophic fuzzy graph.

AMS(2010): 05C12, 03E72, 05C72.

§1. Introduction

Molodtstov dealt with uncertainity and unclear objects using notions of soft set theory [2]. A new set combining the soft sets and fuzzy sets, was then developed and proved to be more effective by Maji.et al [2]. Akram and Nawaz dealed with properties of fuzzy soft graphs [3]. Torra.V in [4] defined the hesitancy fuzzy sets. The order and size in fuzzy graphs was found by Nagoor Gani and Basheer [11]. Gani and Radha [10] worked on regular fuzzy graphs. The concept of constant intuitionistic Fuzzy graph dealt by Karunambigai et.al [5]. Santhi Maheswari and Sekar worked on regular FG in [15], [16]. [9] introduced constant hesitancy fuzzy graph and established some concepts. Pathinathan et.al developed Hesitancy fuzzy graphs [7], and also defined regular hesitancy fuzzy graph [8]. Hesitancy fuzzy soft graphs notions were given by Rajeswari [6].

This article deals with degree of vertex and edge in HFSG. The concept of regular and constant are observed over these HFSG and its characteristics are dealt with.

§2. Preliminaries

Definition 2.1 *A fuzzy graph G, contains a nonempty set V with functions $\sigma : V \to [0,1]$ and $\mu : V \times V \to [0,1]$: $\forall\ u, v \in V$, $\mu(uv) \leq \sigma(u) \wedge \sigma(v)$, where σ and μ are fuzzy vertex set and*

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edge set respectively in G.

Generally, let $N_G = (A, B)$ be neutrosophic fuzzy graph, i.e., let $A = (T_A, I_A, F_A)$ be a neutrosophic fuzzy relation on $B = (T_B, I_B, F_B)$, which is a neutrosophic fuzzy set on set V. If $F_A = 0$ and $F_B = 0$, then such a neutrosophic fuzzy graph is nothing else but a fuzzy graph.

Definition 2.2 *The pair (F, A) is soft set over the universal set, where $A \subseteq E$ and $F : a \to \mathscr{P}(U)$. That is a soft set over U is parametered collection of subsets of U.*

Definition 2.3 *An FSG $\widetilde{G}$ is a 4-tuple, such that*

(1) $\mathscr{G}^*$ *is crisp graph;*

(2) $\mathscr{A}$ *is the parameter set;*

(3) $(\widetilde{\mathscr{F}}, \mathscr{A})$ *is fuzzy soft set over vertex set V;*

(4) $(\widetilde{\mathscr{K}}, \mathscr{A})$ *is fuzzy soft set over edge set E.*

Then, $\left(\widetilde{\mathscr{F}}(a), \widetilde{\mathscr{K}}(a)\right)$ is fuzzy (sub)graph of $\mathscr{G}^*, \forall\ a \in \mathscr{A}$ and can be denoted as $\widetilde{\mathscr{H}}(a)$.

The membership value of the edge in an FSG is given as

$$\widetilde{K}(a)(xy) \leq \min\left\{\widetilde{F}(a)(x), \widetilde{F}(a)(y)\right\}.$$

Definition 2.4 *If $\widetilde{G}$ is an FSG, then the vetex degree is*

$$d_{\widetilde{G}}(u) = \sum_{a_i \in A} (\sum_{u \neq v} \widetilde{\mathscr{K}}(a_i)(uv)).$$

Definition 2.5 *If $\widetilde{G}$ is an FSG, then edge degree of uv is given as*

$$d_{\widetilde{G}}(uv) = d_{\widetilde{G}}(u) + d_{\widetilde{G}}(v) - 2(\sum_{a_i \in A} \widetilde{\mathscr{K}}(a_i)(uv)).$$

Definition 2.6 *Let U be the universal set and E be set of parameters, then HF(U) is set of all hesitant fuzzy sets over U. Then, the pair (F, E) is hesitant fuzzy soft set if $F(e) \in HF(U)$, for every $e \in E$.*

Definition 2.7 *A hesitancy fuzzy graph $\tilde{G} = (\tilde{V}, E)$ such that $\mu_1 : \tilde{V} \to [0, 1]$ (membership), $\gamma_1 : \tilde{V} \to [0, 1]$ (non membership), $\beta_1 : \tilde{V} \to [0, 1]$ (hesitancy membership), also $\mu_1 + \gamma_1 + \beta_1 = 1$ for all vertices.*

Also $E \subseteq \tilde{V} \times \tilde{V}$, where $\mu_1 : \tilde{V} \times \tilde{V} \to [0, 1]$, $\gamma_1 : \tilde{V} \times \tilde{V} \to [0, 1]$, $\beta_1 : \tilde{V} \times \tilde{V} \to [0, 1]$ such that

$$\mu_2(uv) \leq \wedge[\mu_1(u), \mu_1(v)],$$

$$\gamma_2(uv) \leq \vee[\gamma_1(u), \gamma_1(v)],$$

$$\beta_2(uv) \leq \wedge[\beta_1(u), \beta_1(v)]$$

and $0 \leq \mu_2(uv) + \gamma_2(uv) + \beta_2(uv) \leq 1$ for all edges.

Definition 2.8 *For a HFSG, its order is*

$$o(\tilde{G}) = \left(\sum_{a_i \in A, v_i \in V} \mu_1(v_i), \sum_{a_i \in A, v_i \in V} \gamma_1(v_i), \sum_{a_i \in A, v_i \in V} \beta_1(v_i) \right).$$

Definition 2.9 *The size of a HFSG is*

$$s(\tilde{G}) = \left(\sum_{a_i \in A, v_i v_j \in E} \mu_2(v_i v_j), \sum_{a_i \in A, v_i v_j \in E} \gamma_2(v_i v_j), \sum_{a_i \in A, v_i v_j \in E} \beta_2(v_i v_j) \right).$$

§3. Degree in HFSG

Definition 3.1 *Let $\tilde{G}$ be a hesitancy fuzzy soft graph (HFSG). Then,*

$$\begin{aligned} d_\mu(u) &= \sum_{a_i \in A} (\sum_{u \neq v} \tilde{K}_{(a_i)} \mu_2(uv)), \\ d_\gamma(u) &= \sum_{a_i \in A} (\sum_{u \neq v} \tilde{K}_{(a_i)} \gamma_2(uv)), \\ d_\beta(u) &= \sum_{a_i \in A} (\sum_{u \neq v} \tilde{K}_{(a_i)} \beta_2(uv)). \end{aligned}$$

Therefore,

$$d_{\tilde{G}}(u) = \left(d_\mu(u), d_\gamma(u), d_\beta(u) \right).$$

Definition 3.2 *Let $\tilde{G}$ be a HFSG, then total degree of the vertex $v \in V$ is given as*

$$td_{\tilde{G}}(v) = \left(d_\mu(v) + \sum_{a_i \in A} (\mu_1(v)), d_\gamma(v) + \sum_{a_i \in A} (\gamma_1(v)), d_\beta(v) + \sum_{a_i \in A} (\beta_1(v)) \right).$$

Example 3.3 Consider the following HFSG, we demonstrate the above definition.

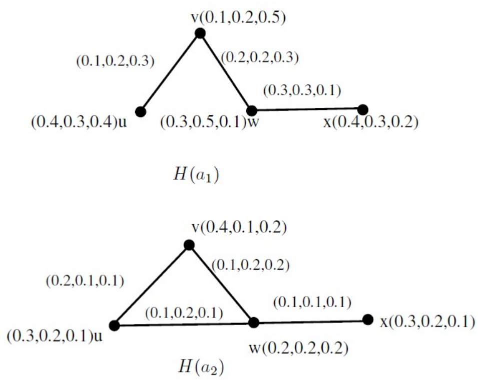

Figure 3.1

The degree of the vertices are found as $d_{\tilde{G}}(u) = (0.4, 0.5, 0.5)$, $d_{\tilde{G}}(v) = (0.6, 0.7, 0.9)$, $d_{\tilde{G}}(w) = (0.7, 0.8, 0.7)$, $d_{\tilde{G}}(x) = (0.4, 0.4, 0.2)$.

The total degree is found as $td_{\tilde{G}}(u) = (1.1, 1.0, 1.0)$, $td_{\tilde{G}}(v) = (1.1, 1.0, 1.6)$, $td_{\tilde{G}}(w) = (1.2, 1.5, 1.0)$, $td_{\tilde{G}}(x) = (1.1, 0.9, 0.5)$.

§4. Constant HFSG

Definition 4.1 *If degree of all the vertices are same, then the HFSG is called constant HFSG (c-HFSG). That is, if, $\tilde{G}$ is a HFSG and if $d_\mu(x_i) = k_1$, $d_\gamma(x_i) = k_2$ and $d_\beta(x_i) = k_3$, $\forall x_i \in V$. Then $\tilde{G}$ is said to be (k_1, k_2, k_3)- HFSG or c-HFSG of degree (k_1, k_2, k_3).*

Example 4.2 The following is a constant-HFSG.

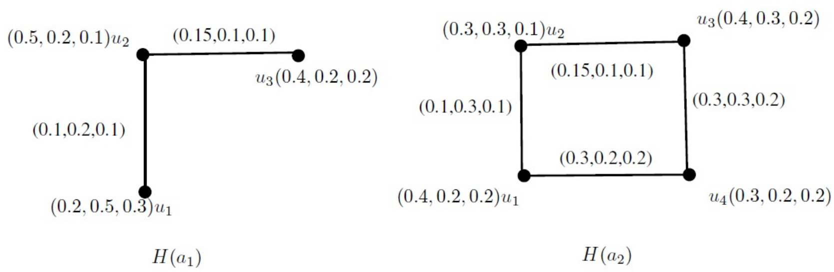

Figure 4.1

The degree of the vetices are $d_{\tilde{G}}(u_1) = (0.6, 0.5, 0.4)$, $d_{\tilde{G}}(u_2) = (0.6, 0.5, 0.4)$, $d_{\tilde{G}}(u_3) = (0.6, 0.5, 0.4)$, $d_{\tilde{G}}(u_4) = (0.6, 0.5, 0.4)$. Here $d_\mu(u_i) = 0.6$, $d_\gamma(u_i) = 0.5$, $d_\beta(u_i) = 0.4$, for all $u_i \in V$. Therefore, it is c-HFSG.

Definition 4.3 *Let $\tilde{G}$ be a HFSG, it is said to be totally constant HFSG (tc-HFSG), if the total degree of all the vertices are same. That is, if a HFSG, having total degree of all its vertices as (l_1, l_2, l_3), then it is (l_1, l_2, l_3)- totally constant HFSG.*

Example 4.4 The following graph illustrates a totally constant HFSG.

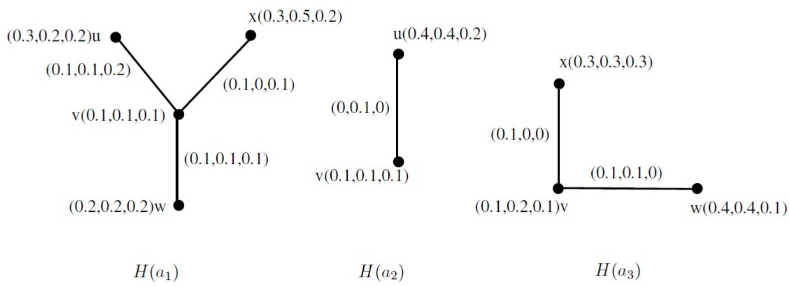

Figure 4.2

The total degree of all the vertices are found to be $(0.8, 0.8, 0.6)$. That is $td_\mu(v_i) = 0.8$, $td_\gamma(v_i = 0.8)$, $td_\beta(v_i) = 0.6$, for all $v_i \in V$. Therefore it is tc-HFSG.

Remark 4.5 A c-HFSG need not be tc-HFSG and vice versa.

Example 4.6 Consider the example 4.2, which is (0.6,0.5,0.4)-constant HFSG. But while finding the total degree of all the vertices, we have $td_{\tilde{G}}(u_1) = (1.2, 1.2, 0.9)$, $td_{\tilde{G}}(u_2) = (1.4, 1.0, 0.6)$, $td_{\tilde{G}}(u_3) = (1.4, 1.0, 0.6)$, $td_{\tilde{G}}(u_4) = (0.9, 0.7, 0.6)$. It is not same, hence it is not totally constant-HFSG.

While taking the example 4.4, which is totally constant-HFSG. But the degree of its vertices are $d_{\tilde{G}}(u) = (0.5, 0.4, 0.3)$, $d_{\tilde{G}}(v) = (0.1, 0.2, 0.2)$, $d_{\tilde{G}}(w) = (0.2, 0.2, 0.1)$, $d_{\tilde{G}}(x) = (0.2, 0, 0.1)$, which are not same, thus it is not constant-HFSG.

Theorem 4.7 *Let $\tilde{G}$ be a c-HFSG. And if $\sum_{a_i \in A, v_i \in V} \tilde{F}(a_i)(v_i)$ is a constant function for all vertices, then $\tilde{G}$ is totally constant-HFSG.*

Proof Suppose $\tilde{G}$ is constant-HFSG, also given that $\sum_{a_i \in A, v_i \in V} \tilde{F}(a_i)(v_i)$ is a constant function. Then

$$\sum_{a_i \in A, u_i \in V} \tilde{F}(a_i)(\mu_1(u_i)) = m_1, \sum_{a_i \in A} \tilde{F}(a_i)(\gamma_1(u_i)) = m_2, \sum_{a_i \in A} \tilde{F}(a_i)(\beta_1(u_i)) = m_3,$$

for $\forall u_i \in V$.

Since $\tilde{G}$ is c-HFSG, let it be $(t_1, t_2, t_3)-$ constant HFSG. This implies that $d_{\tilde{G}}(\mu)(u_i) = t_1$, $d_{\tilde{G}}(\gamma)(u_i) = t_2$, $d_{\tilde{G}}(\beta)(u_i) = t_3$, $\forall u_i \in V$.

Then, the total degree of the vertices are

$$\begin{aligned} td_{\tilde{G}}(u_i) &= d_{\tilde{G}}(\mu)(u_i) + \sum_{a_i \in A} \tilde{F}(a_i)(\mu_1(u_i)), d_{\tilde{G}}(\gamma)(u_i) \\ &\quad + \sum_{a_i \in A} \tilde{F}(a_i)(\gamma_1(u_i)), d_{\tilde{G}}(\beta)(u_i) + \sum_{a_i \in A} \tilde{F}(a_i)(\beta_1(u_i)) \\ &\Rightarrow td_{\tilde{G}}(u_i) = (t_1 + m_1, t_2 + m_2, t_3 + m_3), \forall u_i \in V. \end{aligned}$$

Therefore, it is totally constant HFSG. □

Note 4.8 For a HFSG $\tilde{G}$, its order is given by

$$o(\tilde{G}) = \sum_{a_i \in A} o(H(a_i)).$$

Note 4.9 For a HFSG $\tilde{G}$, its size is

$$s(\tilde{G}) = \sum_{a_i \in A} \sum_{uv \in E} (\mu_2, \gamma_2, \beta_2)(uv).$$

Result 4.10 *The size of a c-HFSG or a (k_1, k_2, k_3) c-HFSG is given by*

$$\left[\frac{hk_1}{2}, \frac{hk_2}{2}, \frac{hk_3}{2}\right],$$

where $h = \left|\tilde{G}\right|$.

Observation 4.11 The following are observed using the above defined graphs.

(1) Let $\tilde{G}$ be a (l_1, l_2, l_3) totally constant-HFSG, then

$$2s(\tilde{G}) + o(\tilde{G}) = (hl_1, hl_2, hl_3),$$

where $h = |V|$.

(2) For $\tilde{G}$ be a (t_1, t_2, t_3) c-HFSG and (l_1, l_2, l_3) tc-HFSG, then the order is given as

$$o(\tilde{G}) = (h(l_1 - t_1), h(l_2 - t_2), h(l_3 - t_3)),$$

where $h = |V|$.

§5. Regular HFSG

Definition 5.1 *A HFSG $\tilde{G}$ is regular, when $(d_\mu, d_\gamma, d_\beta)$ (degree) of all the vertices are the same constant. That is, if $\tilde{G}$ is a $((\mu_{1i}, \gamma_{1i}, \beta_{1i}), (\mu_{2i}, \gamma_{2i}, \beta_{2i}))$ HFSG and if $d_\mu(v_i) = d_\beta(v_i) = d_\beta(v_i) = m$, $\forall v \in V$ and $ainA$, then $\tilde{G}$ is m-regular HFSG.*

Example 5.2 Examine the following example.

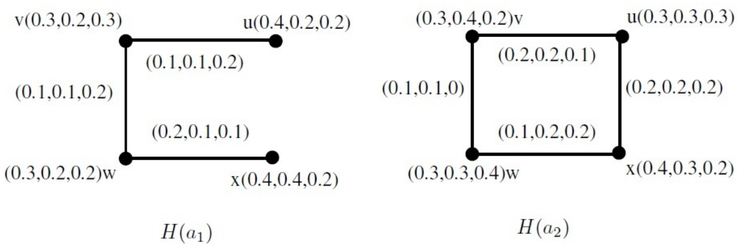

Figure 5.1

In this the degree of all the vertices are found to be $d_{\tilde{G}}(u) = (0.5, 0.5, 0.5)$, $d_{\tilde{G}}(v) = (0.5, 0.5, 0.5)$, $d_{\tilde{G}}(w) = (0.5, 0.5, 0.5)$, $d_{\tilde{G}}(x) = (0.5, 0.5, 0.5)$. Here $d_\mu(v_i) = 0.5$, $d_\gamma(v_i) = 0.5$, $d_\beta(v_i) = 0.5$, for all $v_i \in V$. Therefore it is regular HFSG or 0.5-regular HFSG.

Definition 5.3 *A HFSG $\tilde{G}$ is totally regular, when total degree of all vertices are the alike. That is if $td_\mu(v_i) = td_\beta(v_i) = td_\beta(v_i) = k$, $\forall v \in V$ and $a \in A$, $\Rightarrow \tilde{G}$ is k-totally regular HFSG.*

Example 5.4 Consider the graph in Figure 5.2 following.

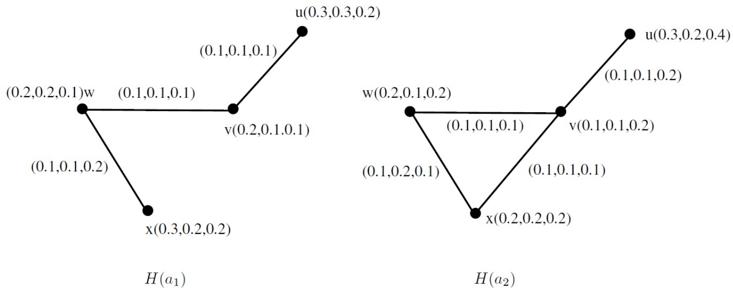

Figure 5.2

In this the total degree of all the vertices are found as $td_{\tilde{G}}(u) = (0.8, 0.8, 0.8)$, $td_{\tilde{G}}(v) = (0.8, 0.8, 0.8)$, $td_{\tilde{G}}(w) = (0.8, 0.8, 0.8)$, $td_{\tilde{G}}(x) = (0.8, 0.8, 0.8)$. Here $td_{\mu}(v_i) = 0.8$, $td_{\gamma}(v_i) = 0.8$, $td_{\beta}(v_i) = 0.8$, for all $v_i \in V$. Therefore it is totally regular HFSG or 0.8-totally regular HFSG.

Definition 5.5 *Let $\tilde{G}$ be a hesitancy fuzzy soft graph. The degree of the edge uv in E is defined as*

$$deg_{\tilde{G}}(uv) = d_{\tilde{G}}(u) + d_{\tilde{G}}(v) - 2((\mu_2, \gamma_2, \beta_2)(uv)).$$

Definition 5.6 *Let $\tilde{G}$ be a HFSG. The total degree of the edge uv in E is defined as*

$$tdeg_{\tilde{G}}(uv) = d_{\tilde{G}}(u) + d_{\tilde{G}}(v) - ((\mu_2, \gamma_2, \beta_2)(uv)).$$

Example 5.7 We consider the below hesitancy fuzzy soft graph.

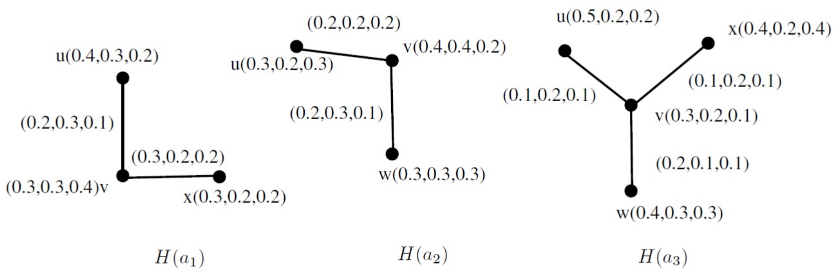

Figure 5.3

The degree of the edges are $deg(uv) = (0.8, 0.8, 0.5)$, $deg(vw) = (0.9, 1.1, 0.7)$, $deg(vx) = (0.9, 1.1, 0.6)$. The total degree of the edges are $tdeg(uv) = (1.3, 1.5, 0.9)$, $tdeg(vw) = (1.3, 1.5, 0.9)$, $tdeg(vx) = (1.3, 1.5, 0.9)$.

Definition 5.8 *A HFSG $\tilde{G}$ is edge regular, if the edge degree of all the edges are alike. That is*

$$deg_{\tilde{G}}\mu_2(v_iv_j) = deg_{\tilde{G}}\gamma_2(v_iv_j) = deg\tilde{G}_{\beta_2}(v_iv_j) = p.$$

Then, $\tilde{G}$ is called p-edge regular HFSG.

Definition 5.9 *A HFSG $\tilde{G}$ is edge totally regular, if the total edge degree of all the edges are alike. That is,*

$$tdeg_{\tilde{G}}\mu_2(v_iv_j) = tdeg\tilde{G}_{\gamma_2}(v_iv_j) = tdeg\tilde{G}_{\beta_2}(v_iv_j) = r.$$

Then, $\tilde{G}$ is called r- totally edge regular hesitancy fuzzy soft graph.

Example 5.10 We use below graph to explain the definition.

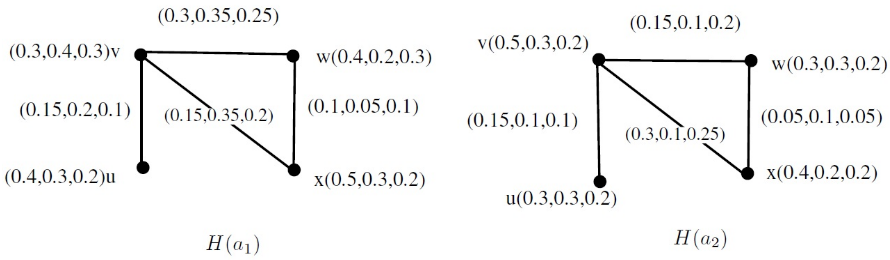

Figure 5.4

The edge degree are given as $deg_{\tilde{G}}(uv) = (0.9, 0.9, 0.9)$, $deg_{\tilde{G}}(vw) = (0.9, 0.9, 0.9)$, $deg_{\tilde{G}}(wx) = (0.9, 0.9, 0.9)$, $deg_{\tilde{G}}(vx) = (0.9, 0.9, 0.9)$. Therefore the graph is 0.9-edge regular HFSG.

Example 5.11 The following graph demonstrates the above definition.

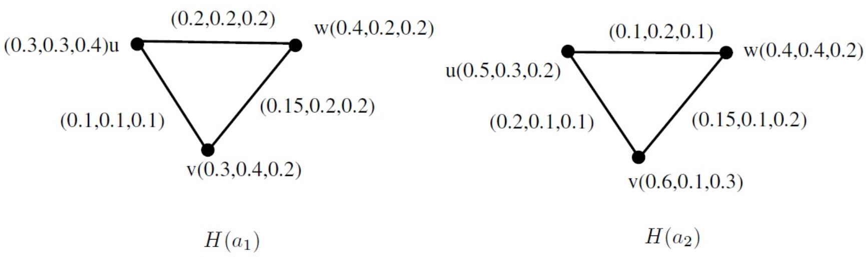

Figure 5.5

The total edge degree are found as $tdeg_{\tilde{G}}(uv) = (0.9, 0.9, 0.9)$, $tdeg_{\tilde{G}}(vw) = (0.9, 0.9, 0.9)$, $tdeg_{\tilde{G}}(wu) = (0.9, 0.9, 0.9)$. Thus the graph is 0.9-totally edge regular HFSG.

Remark 5.12 A HFSG which is edge regular, not necessarily be total edge regular and vice versa.

Remark 5.13 A regular HFSG can be constant HFSG, but the converse not necessarily true.

Remark 5.114 A totally regular HFSG can be totally constant HFSG, but converse may not be true.

Theorem 5.15 *Suppose $\tilde{G}$ is a HFSG and if its subgraphs $H(a_i), a_i \in A$ are fuzzy cycles of even length, with membership values of alternate edges alike, then $\tilde{G}$ is constant HFSG.*

Proof Consider the subgraphs of $\tilde{G}$, $H(a_i), a_i \in A$. Let us take only two parameters a_1 and a_2, such that the membership value of edges in $H(a_1)$ and $H(a_2)$ are alternatively same.

Let the membership value of the edges, e_i in $H(a_1)$ is (l_1, m_1, n_1) and (l_2, m_2, n_2), when i is odd and even respectively. And for edges e_j in $H(a_2)$, the membership value is (p_1, q_1, r_1) and (p_2, q_2, r_2), when j is odd and even respectively. Then we have, the degree of vertices as

$$d_{\tilde{G}}(v_i) = (l_1 + p_1 + l_2 + p_2, m_1 + q_1 + m_2 + q_2, n_1 + r_1 + n_2 + r_2)$$

for all $v_i \in V$, which

$$\Rightarrow (d_\mu(\tilde{G}), d_\gamma(\tilde{G}), d_\beta(\tilde{G}))(v_i) = \text{constant}$$

for all $v_i \in V$. Thus, it is c-HFSG. □

Theorem 5.16 *If $\tilde{G}$, a c-HFSG satisfying the conditions of above theorem, then it is totally constant HFSG, when $(\mu_1, \gamma_1, \beta_1)$ is constant for all the vertices.*

Proof Suppose $\tilde{G}$ is c-HFSG, then we have $(d_\mu(\tilde{G}), d_\gamma(\tilde{G}), d_\beta(\tilde{G}))(v_i) = constant$ for all $v_i \in V$. Also given that $(\mu_1, \gamma_1, \beta_1)$ is constant for all vertices, then the total degree of all the vertices is also constant, since

$$td_{\tilde{G}}(v) = \left(d_\mu(v) + \sum_{a_i \in A} (\mu_1(v)), d_\gamma(v) + \sum_{a_i \in A} (\gamma_1(v)), d_\beta(v) + \sum_{a_i \in A} (\beta_1(v)) \right),$$

which $\Rightarrow \tilde{G}$ is totally constant HFSG. □

Theorem 5.17 *Suppose $\tilde{G}$ is a HFSG and if its subgraphs $H(a_i), a_i \in A$ are fuzzy cycles of any length and if $\sum_{a_i \in A, e_i \in E} K(a_i)(e_i)$, are alike and same constant for all the edges, then $\tilde{G}$ is regular HFSG.*

Proof Given $\tilde{G}$ is a HFSG and also $\sum_{a_i \in A, e_i \in E} K(a_i)(e_i)$ are alike and same constant for all edges. Let us consider any two subgraphs of $\tilde{G}$ with parameters set a_1 and a_2, then we have

$$\sum_{a_i \in A, e_i \in E} K(a_i)(e_i) = (m, m, m).$$

Then, the degree of the vertices are $d_{\tilde{G}}(v_i) = (2m, 2m, 2m)$ for all $v_i \in V$. This implies that $\tilde{G}$ is regular-HFSG. □

Theorem 5.18 *Suppose $\tilde{G}$ is a HFSG and its subgraphs are fuzzy cylcles of any length and if*

$$\sum_{a_i \in A, e_i \in E} K(a_i)(e_i), \quad \sum_{a_i \in A, v_i \in V} F(a_i)(v_i)$$

are alike and same constant for all edges and vertices respectively, then $\tilde{G}$ is both regular and totally regular hesitancy fuzzy soft graph.

Proof Let us consider $\tilde{G}$ such that

$$\sum_{a_i \in A, e_i \in E} K(a_i)(e_i)$$

are alike and same constant for all vertices, then by above theorem, $\tilde{G}$ is regular HFSG. Let it be (m, m, m) regular HFSG.

Let

$$\sum_{a_i \in A, v_i \in V} F(a_i)(v_i) = (k, k, k)$$

for all vertices. Considering the total degree of all the vertices, it is found that

$$td_{\tilde{G}}(v_i) = (m + k, m + k, m + k) \Rightarrow \tilde{G}$$

is totally regular HFSG. □

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