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2nd-NEIGHBOURLY IRREGULAR FUZZY GRAPHS

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ABSTRACT

In this paper, 2^{nd}-Neighbourly irregular fuzzy graphs and 2^{nd}-Neighbourly totally irregular fuzzy graphs are defined. Comparative study between 2^{nd}-Neighbourly irregular fuzzy graph and 2^{nd}-Neighbourly totally irregular fuzzy graph is done. Property of 2^{nd}-Neighbourly irregular fuzzy graph and 2^{nd}-Neighbourly totally irregular fuzzy graph are discussed. 2^{nd}-Neighbourly irregularity on fuzzy graphs whose underlying graphs are cycle c_n, a Barbell graph $B_{n,m}$, Sub ($B_{n,m}$) are studied.

Key words: *degree of a vertex in fuzzy graph, irregular fuzzy graph, neighbourly irregular fuzzy graph, neighbourly totally irregular fuzzy graph.*

AMS subject classification: *05C12, 03E72, 05C72.*

1. INTRODUCTION

In 1736, Euler first introduced the concept of graph theory. Graph theory is a very useful tool for solving combinatorial problems in different areas such as operations research, optimization, topology, geometry, number theory and computer science. Fuzzy set theory was first introduced by Zadeh in 1965. Fuzzy set theory has emerged as a potential area of interdisciplinary research and fuzzy graph theory is of recent interest. The first definition of fuzzy graph was introduced by Haufmann in 1973 based on Zadeh's fuzzy relations in 1971. In 1975, Rosenfeld introduced the concept of fuzzy graphs.

Now, fuzzy graphs have been witnessing a tremendous growth and finds application in many branches of engineering and technology. A. Nagoorgani and S.R. Latha introduced irregular fuzzy graphs, total degree and totally irregular fuzzy graphs. They also introduced the concept of neighborly irregular fuzzy graphs and highly irregular fuzzy graphs [8]. S. Ravi Narayanan and N. R. Santhi Maheswari introduced 2^{nd} – highly irregular fuzzy graphs [10]. These motivates us to introduce 2^{nd}- Neighbourly irregular fuzzy graphs and 2^{nd}- Neighbourly totally irregular fuzzy graphs and discussed some of its properties.

2. PRELIMINARIES

We present some known definitions related to fuzzy graphs for ready reference to go through the work presented in this paper.

Definition 2.1: A fuzzy graph G:(σ, μ) is a pair of functions (σ, μ), where σ: V → [0, 1] is a fuzzy subset of a non empty set V and μ: V X V→ [0, 1] is a symmetric fuzzy relation on σ such that for all u, v in V, the relation $\mu(u, v) \leq \sigma(u) \wedge \sigma(v)$ is satisfied. A fuzzy graph G is called complete fuzzy graph if the relation $\mu(u, v) = \sigma(u) \wedge \sigma(v)$ is satisfied.

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Definition 2.2: Let G:(σ, μ) be a fuzzy graph on $G^*(V, E)$. The degree of a vertex u in G is denoted by d(u) and is defined as d(u)=∑ μ(uv), for all uv ∈ E.

Definition 2.3: Let G: (σ, μ) be a fuzzy graph on $G^*(V, E)$. The total degree of a vertex u in G is denoted by td(u) and is defined as td(u)=∑ μ(uv) + σ(u), for all u ∈ V. It can also be defined as td(u)=d(u) + σ(u).

Definition 2.4: Let G: (σ, μ) be a fuzzy graph on $G^*(V, E)$. Then G is said to be an irregular fuzzy graph if at least two vertices of G has distinct degrees.

Definition 2.5: Let G: (σ, μ) be a fuzzy graph on $G^*(V, E)$. Then G is said to be neighbourly irregular fuzzy graph if every two adjacent vertices in G have distinct degrees.

Definition 2.6: Let G: (σ, μ) be a fuzzy graph on $G^*(V, E)$. Then G is said to be neighbourly totally irregular fuzzy graph if every two adjacent vertices in G have distinct total degrees.

Definition 2.7: Let G: (σ, μ) be a fuzzy graph on $G^*(V, E)$. Then G is said to be strongly irregular fuzzy graph if every pair of vertices have distinct degrees.

Definition 2.8: Let G: (σ, μ) be a fuzzy graph on $G^*(V, E)$. Then G is said to be strongly totally irregular fuzzy graph if every pair of vertices have distinct total degrees.

Definition 2.9: The 2^{nd}- neighbourhood of a vertex v in G is defined as $N_2(v)$ ={u: u is at a distance 2 away from v}.

3. 2^{nd}-NEIGHBOURLY IRREGULAR FUZZY GRAPHS

Definition 3.1: Let G: (σ, μ) be a fuzzy graph on $G^*(V, E)$. Then G is said to be a 2^{nd}- Neighbourly Irregular Fuzzy Graph if every pair of vertices which are at a distance two away from each other in G have distinct degrees.

Example 3.2: Consider a fuzzy graph on G^*: (V, E), a cycle of length 5.

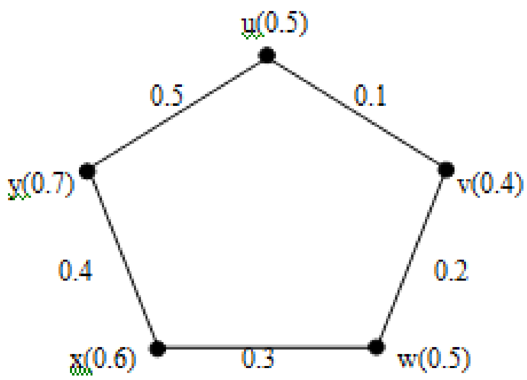

Figure-1

Here, $d(u)=0.6, d(v)=0.3, d(w)=0.5, d(x)=0.7, d(y)=0.9$
$N_2(u)=\{x, w\}$ and also $d(u) \neq d(x), d(u) \neq d(w)$.
$N_2(v)=\{y, x\}$ and also $d(v) \neq d(y), d(v) \neq d(x)$.
$N_2(w)=\{u, y\}$ and also $d(w) \neq d(u), d(w) \neq d(y)$.
$N_2(x)=\{u, v\}$ and also $d(x) \neq d(u), d(x) \neq d(v)$.
$N_2(y)=\{v, w\}$ and also $d(y) \neq d(v), d(y) \neq d(w)$.

So, every pair of vertices which are at a distance two away from each other have distinct degrees. Hence G is 2^{nd}-Neighbourly irregular fuzzy graph.

Definition 3.3: Let G: (σ, μ) be a fuzzy graph on $G^*(V, E)$. Then G is said to be a 2^{nd}-Neighbourly Totally Irregular Fuzzy Graph if every pair of vertices which are at a distance two away from each other have distinct total degrees.

Example 3.4: Consider a fuzzy graph on $G^*(V, E)$.

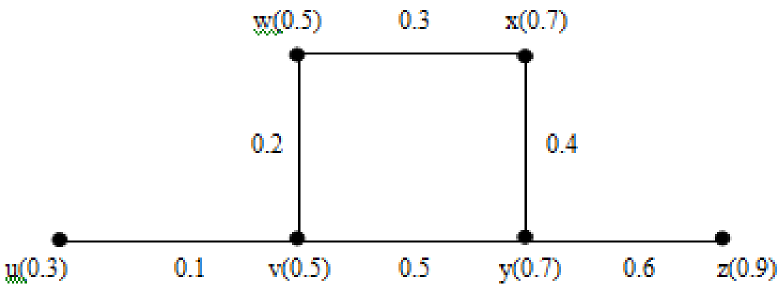

Figure-2

Here, $d(u)=0.1$, $d(v)=0.8$, $d(w)=0.5$, $d(x)=0.7$, $d(y)=1.5$ and $d(z)=0.6$.

Also, $td(u)=0.4$, $td(v)=1.3$, $td(w)=1$, $td(x)=1.4$, $td(y)=2.2$ and $td(z)=1.5$.
$N_2(u)=\{w, y\}$, also $td(u) \neq td(w)$ and $td(u) \neq td(y)$.
$N_2(v)=\{x, z\}$, also $td(v) \neq td(x)$ and $td(v) \neq td(z)$.
$N_2(w)=\{u, y\}$, also $td(w) \neq td(u)$ and $td(w) \neq td(y)$.
$N_2(x)=\{v, z\}$, also $td(x) \neq td(v)$ and $td(x) \neq td(z)$.
$N_2(y)=\{u, w\}$, also $td(y) \neq td(w)$ and $td(y) \neq td(w)$.
$N_2(z)=\{x, v\}$, also $td(z) \neq td(x)$ and $td(z) \neq td(v)$.

So, every pair of vertices which are at a distance two away from each other have distinct total degrees.

Hence G is 2nd-Neighbourly totally irregular fuzzy graph.

Remark 3.5: A 2nd-Neighbourly irregular fuzzy graph need not be 2nd-Neighbourly totally irregular fuzzy graph.

Example 3.6: Consider a fuzzy graph on G^*:(V, E), a cycle of length 5.

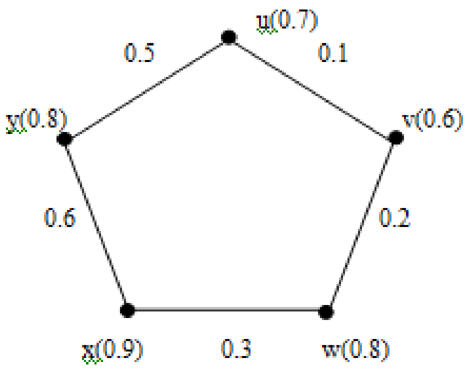

Figure-3

Here, $d(u)=0.6$, $d(v)=0.3$, $d(w)=0.5$, $d(x)=0.9$, $d(y)=1.1$.

Also, $td(u)=1.3$, $td(v)=0.9$, $td(w)=1.3$, $td(x)=1.8$, $td(y)=1.9$.

Every pair of vertices which are at a distance two away from each other have distinct degrees. Hence G is 2nd-Neighbourly irregular fuzzy graph.

But the vertices *u* and *w* are at a distance two away from each other have same total degrees. Hence G is not 2nd-Neighbourly totally irregular fuzzy graph.

Remark 3.7: A 2nd-Neighbourly totally irregular fuzzy graph need not be 2nd- Neighbourly irregular fuzzy graph.

Example 3.8: Consider a fuzzy graph on $G^*(V, E)$.

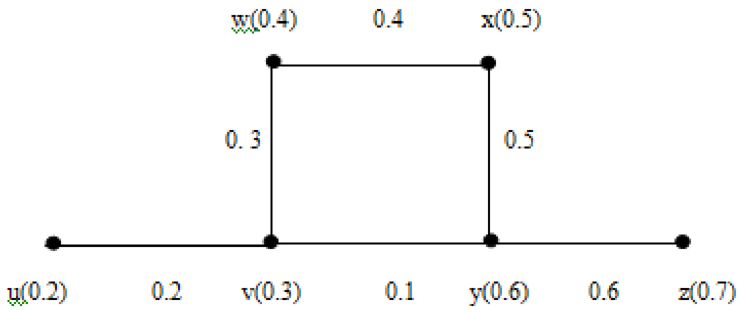

Figure-4

Here, $d(u)=0.2$, $d(v)=0.6$, $d(w)=0.7$, $d(x)=0.9$, $d(y)=1.2$ and $d(z)=0.6$.

Also, $td(u)=0.4$, $td(v)=0.9$, $td(w)=1.1$, $td(x)=1.4$, $td(y)=1.8$ and $td(z)=1.3$.

Every pair of vertices which are at a distance two away from each other have distinct total degrees. Hence G is 2^{nd}-Neighbourly totally irregular fuzzy graph.

But the vertices *v* and *z* are at a distance two away from each other having same degree. Hence G is not 2^{nd}-neighbourly irregular fuzzy graph.

Theorem 3.9: *Let G: (σ, μ) be a fuzzy graph on $G^*(V, E)$. If G is 2^{nd}-Neighbourly irregular fuzzy graph and σ is a constant function, then G is 2^{nd}-Neighbourly totally irregular fuzzy graph.*

Proof: Let G: (σ, μ) be a 2^{nd}-Neighbourly irregular fuzzy graph. Then every pair of vertices which are at a distance two away from each other have distinct degrees. Let v and w be the vertices which are at a distance two away from each other such that $d(v)=k_1$ and $d(w)=k_2$, where $k_1 \neq k_2$. Also, assume that $\sigma(u)=c$, for all $u \in V$. Suppose, $td(v)=td(w)$ $\Rightarrow d(v)+ \sigma(v) = d(w) + \sigma(w) \Rightarrow k_1+c = k_2+c \Rightarrow k_1=k_2$. Which is a contradiction. So, $td(v) \neq td(w)$. Hence the vert ices v and w have distinct total degrees provided σ is a constant function. This is true for all the vertices which are at a distance two away from each other in G. Hence G is 2^{nd}- Neighbourly totally irregular fuzzy graph.

Theorem 3.10: *Let G: (σ, μ) be a fuzzy graph on $G^*(V,E)$. If G is 2^{nd}- Neighbourly totally irregular fuzzy graph and σ is a constant function, then G is 2^{nd}-Neighbourly irregular fuzzy graph.*

Proof: Let G: (σ, μ) be a 2^{nd}-Neighbourly totally irregular fuzzy graph. Then every pair of vertices which are at a distance two away from each other have distinct total degrees. Let v and w be the vertices which are at a distance two away from each other such that $td(v) = k_1$ and $td(w) = k_2$, where $k_1 \neq k_2$. Also, assume that $\sigma(u) = c$, for all $u \in V$. Suppose, $td(v) \neq td(w) \Rightarrow d(v) + \sigma(v) \neq d(w) + \sigma(w) \Rightarrow d(v) \neq d(w)$. Hence the vertices v and w have distinct total degrees provided σ is a constant function. This is true for all the vertices which are at a distance two away from each other in G. Hence G is 2^{nd}- Neighbourly irregular fuzzy graph.

Remark 3.11: *The theorems 3.9 and 3.10 jointly yield the following result. Let G be a fuzzy graph on $G^*(V, E)$. If σ is a constant function, then G is 2^{nd}-Neighbourly irregular fuzzy graph if and only if G is 2^{nd}-Neighbourly totally irregular fuzzy graph.*

Remark 3.12: *Let G: (σ, μ) be a fuzzy graph on $G^*(V, E)$. If G is both 2^{nd}- Neighbourly irregular fuzzy graph and 2^{nd}-Neighbourly totally irregular fuzzy graph, then σ need not be a constant function.*

Example 3.13: Consider a fuzzy graph G: (σ, μ) on $G^*(V, E)$.

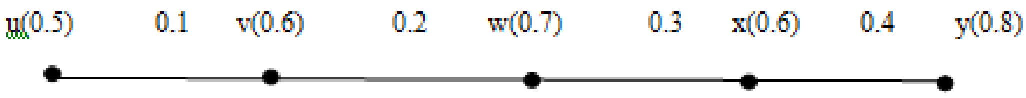

Figure-5

Here, G is both 2^{nd}- Neighbourly irregular fuzzy graph and 2^{nd}-Neighbourly totally irregular fuzzy graph. But σ is not a constant function.

Theorem 3.14: *Let G: (σ, μ) be a fuzzy graph on $G^*(V, E)$. If G is strongly irregular fuzzy graph then G is 2^{nd}-Neighbourly irregular fuzzy graph.*

Proof: Let G: (σ, μ) be a fuzzy graph on $G^*(V, E)$. Assume that G is strongly irregular fuzzy graph. Then ever pair of vertices in G have distinct degrees ⇨ all the vertices in G have distinct degrees. So, every pair of vertices which are at a distance two away from each other have distinct degrees in G. Hence G is 2^{nd}- Neighbourly irregular fuzzy graph.

Theorem 3.15: *Let G: (σ, μ) be a fuzzy graph on $G^*(V, E)$. If G is strongly totally irregular fuzzy graph then G is 2^{nd}-Neighbourly totally irregular fuzzy graph.*

Proof: Proof is similar to the above Theorem 3.14.

Remark 3.16: *The converse of above Theorems 3.14 and 3.15 need not be true.*

Example 3.17: Consider a fuzzy graph on G^*: (V, E).

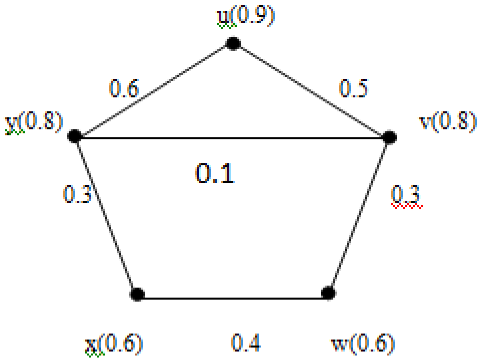

Figure-6

Here, $d(u) = 1.1, d(v) = 0.9, d(w) = 0.7, d(x) = 0.7, d(y) = 1$ and
td(u) = 2, td(v) = 1.7, td(w) = 1.3, td(x) =1.3, td(y)=1.8.

So, every pair of vertices which are at a distance two away from each other have distinct degrees. Hence G is 2^{nd}-neighbourly irregular fuzzy graph.

But the vertices *w* and *x* have same degrees. Hence G is not strongly irregular fuzzy graph.

Also, every pair of vertices which are at a distance two away from each other have distinct total degrees.

Hence G is 2^{nd}-neighbourly totally irregular fuzzy graph.

But the vertices *w* and *x* have same total degree. Hence G is not strongly totally irregular fuzzy graph.

4. 2^{nd}-NEIGHBOURLY IRREGULARITY ON CYCLE WITH SOME SPECIFIC MEMBERSHIP FUNCTIONS

Theorem 4.1: *Let G: (σ, μ) be a fuzzy graph on $G^*(V, E)$, an even cycle of length n. If σ takes distinct membership values and μ is constant function or alternate edges takes same membership values, then G is 2^{nd}-Neighbourly totally irregular fuzzy graph.*

Proof:
Case-1: Suppose μ is a constant function, d(u)=k, for all u ∈ V. We have td(u)=d(u) + σ(u). Since σ takes distinct membership values, every pair of vertices which are at a distance two away from each other have distinct total degrees. Hence G is 2^{nd}-Neighbourly totally irregular fuzzy graph.

Case-2: Alternate edges takes same membership values

Let $\mu(e_i) = \begin{cases} k_1 & if \;\; i \;\; is \;\; odd \\ k_2 & if \;\; i \;\; is \;\; even \end{cases}$

Let *w* and *y* be the vertices which are at a distance two away from each other Since σ takes distinct membership values, let $\sigma(w) = c_1$ and $\sigma(y) = c_2$. Now, $td(w) = c_1+k_1+k_2$ and $td(y) = c_2+k_1+k_2 \Rightarrow td(w) \neq td(y)$. So, the vertices *w* and *y* have distinct total degrees. This is true for every pair of vertices which are at a distance two away from each other in G. Hence G is 2^{nd}-Neighbourly totally irregular fuzzy graph.

Theorem 4.2: *Let G: (σ, μ) be a fuzzy graph on $G^*(V, E)$, a cycle of length n. If the membership values of the edges $e_1,e_2,...,e_n$ are respectively $c_1,c_2,...,c_n$ such that $c_1<c_2<...<c_n$, then G is 2^{nd}-Neighbourly irregular fuzzy graph.*

Proof: Let $e_1, e_2,...,e_n$ be the edges of the cycle C_n taking membership values $c_1, c_2,...,c_n$

Then $d(v_1)=c_1+c_n$ and for i = 2,3....n, $d(v_i) = c_{i-1}+c_i$.

Here, all the vertices have distinct degrees. So, every pair of vertices which are at a distance two away from each other have distinct degrees. Hence G is 2^{nd}-Neighbourly irregular fuzzy graph.

Remark 4.3: *Even if the membership values of the edges $e_1, e_2,...,e_n$ are respectively $c_1, c_2,...,c_n$ such that $c_1<c_2<...<c_n$ then G is not 2^{nd}-Neighbourly totally irregular fuzzy graph.*

Example 4.4: Consider a fuzzy graph on $G^*(V, E)$, a cycle of length 6.

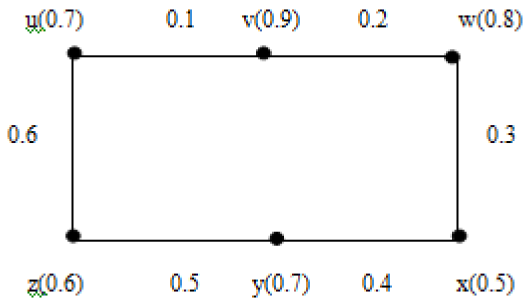

Figure-7

Here, the vertices v and x which are at a distance two away from each other having same total degree.

Hence G is not 2^{nd}-Neighbourly totally irregular fuzzy graph.

Theorem 4.5: *Let G: (σ, μ) be a fuzzy graph on $G^*(V, E)$, a cycle of length n. If the membership values of the edges $e_1,e_2,...,e_n$ are respectively $c_1,c_2,...,c_n$ such that $c_1>c_2>...>c_n$, then G is 2^{nd}-Neighbourly irregular fuzzy graph.*

Proof: Proof is similar to above Theorem 4.2

Remark 4.6: *Even if the membership values of the edges $e_1, e_2,...,e_n$ are respectively $c_1, c_2,...,c_n$ such that $c_1>c_2>...>c_n$, then G is not 2^{nd}-Neighbourly totally irregular fuzzy graph.*

Example 4.7: Consider a fuzzy graph on $G^*(V, E)$, a cycle of length 6.

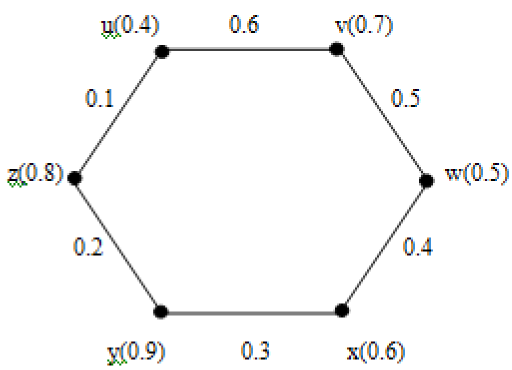

Figure-8

Here, the vertices w and y which are at a distance two away from each other having same total degree.

Hence G is not 2^{nd}-Neighbourly totally irregular fuzzy graph.

Remark 4.8: *Let G:(σ, μ) be a fuzzy graph on $G^*(V, E)$, a cycle of length n. If the membership values of the edges $e_1, e_2,...,e_n$ are respectively $c_1, c_2,...,c_n$ are all distinct, then G need not be 2^{nd}-Neighbourly irregular fuzzy graph.*

Example 4.9: Consider a fuzzy graph on $G^*(V, E)$, a cycle of length 6.

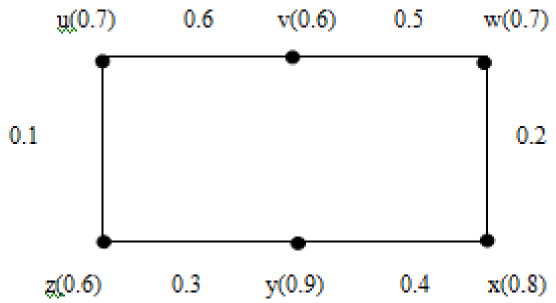

Figure-9

Here, the vertices w and y which are at a distance two away from each other having same degree.

Hence G is not 2^{nd}-neighbourly irregular fuzzy graph.

5. 2^{nd}-NEIGHBOURLY IRREGULARITY ON BARBELL GRAPH WITH SPECIFIC MEMBERSHIP FUNCTIONS

Theorem 5.1: *Let G: (σ, μ) be a fuzzy graph on $G^*(V, E)$ which is a barbell graph $B_{m,n}$. If μ is constant function and σ takes distinct membership values, then G is 2^{nd}-Neighbourly totally irregular fuzzy graph.*

Proof: Let $v_1, v_2,...,v_n$ be the vertices adjacent to vertex x and $u_1, u_2,...,u_n$ be the vertices adjacent to vertex y and xy is the middle edge. Since μ is constant function, μ(uv) = c, for all uv ∈ E. Then all the pendant edges have same degrees. Since the vertices take distinct membership values, the total degrees of all the vertices are distinct. So, every pair of vertices which are at a distance two away from each other have distinct total degrees. Hence G is 2^{nd}-Neighbourly totally irregular fuzzy graph.

Remark 5.2: *Even if μ is constant function and σ takes distinct membership values, then G need not be 2^{nd}-neighbourly irregular fuzzy graph.*

Example 5.3: Consider a fuzzy graph on $G^*(V, E)$, a barbell graph $B_{3,2}$

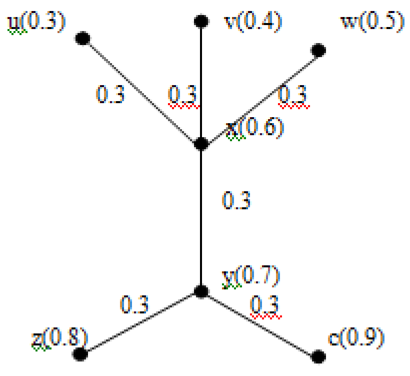

Figure-10

Here, the vertices v and w which are at a distance two away from each other having same degree. Hence G is not 2^{nd}-neighbourly irregular fuzzy graph.

Remark 5.4: *The converse of Theorem 5.1 need not be true. For Example, in above Figure.10, if we replace membership value of edge xy by 0.4 then μ(xy)=0.4.*

Example 5.5: Consider a fuzzy graph on $G^*(V, E)$, a barbell graph $B_{3,2}$

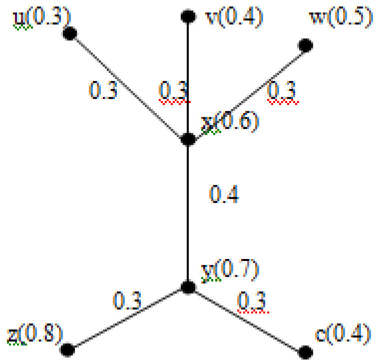

Figure-11

The graph is 2nd-Neighbourly totally irregular fuzzy graph. But neither μ is a constant function nor σ takes distinct membership values.

Theorem 5.6: *Let G:(σ, μ) be a fuzzy graph on $G^*(V, E)$ which is a barbell graph $B_{m,n}$. If the pendant edges have same membership values less than or equal to the membership values of middle edge and σ takes distinct membership values, then G is 2nd-Neighbourly totally irregular fuzzy graph.*

Proof: Let σ takes distinct membership values,If the pendant edges have same membership values then,

$$\text{Let } \mu(e_i) = \begin{cases} c_1 & \text{if } e_i \text{ is pendant edge} \\ c_2 & \text{if } e_i \text{ is middle edge} \end{cases}$$

If $c_1=c_2$, then μ is constant function and hence by theorem 5.1, G is 2nd-neighbourly totally irregular fuzzy graph.

If $c_1< c_2$, $d(v_i) = c_1$ if e_i is pendant edge. But since σ takes distinct membership values, total degrees of all the vertices are distinct. So, every pair of vertices which are at a distance two away from each other has distinct total degrees. Hence G is 2nd-Neighbourly totally irregular fuzzy graph.

Remark 5.7: *Even if the pendant edges have same membership value less than membership value of middle edge, G need not be 2nd-Neighbourly irregular fuzzy graph, since the degrees of pendant edges are same.*

Theorem 5.8: *Let G: (σ, μ) be a fuzzy graph on $G^*(V, E)$ which is a sub $(B_{n,m})$. If μ is constant function and σ takes distinct membership values, then G is 2nd-Neighbourly totally irregular fuzzy graph.*

Proof: Let $v_1, v_2,...,v_n$ be the vertices adjacent to vertex x and $u_1, u_2,...,u_n$ be the vertices adjacent to vertex y and xy is the middle edge. Subdivide each edge of $B_{n,m}$. Then the additional edges are xw_i, w_iv_i $(1 \le i \le n)$ and yt_i, t_iu_i $(1 \le i \le n)$ and two more edges xs, sy. If μ is constant function say μ(uv)=c, for all uv ∈ E.

The vertices w_i, t_i are all have same degrees. But since σ takes distinct membership values, every pair of vertices which are at a distance two away from each other have distinct total degrees. Hence G is 2nd-Neighbourly totally irregular fuzzy graph.

Remark 5.9: *Even if μ is constant function and σ takes distinct membership values, then G need not be 2nd-neighbourly irregular fuzzy graph, since all the additional vertices w_i have same degree.*

Remark 5.10: *The converse of Theorem 5.8 need not be true.*

Example 5.11: Consider a fuzzy graph on $G^*(V, E)$.

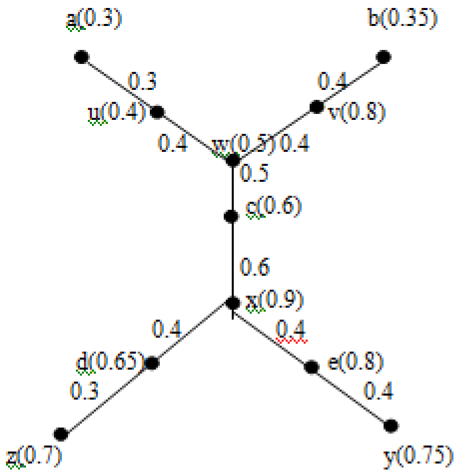

Figure-12

The graph is 2^{nd}-Neighbourly totally irregular fuzzy graph. But neither μ is a constant function nor σ takes distinct membership values.

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