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TOTALLY REGULAR PROPERTY OF JOIN OF INTUITIONISTIC FUZZY GRAPHS

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Abstract

Totally regular property of union of two intuitionistic fuzzy graphs need not be a totally regular intuitionistic fuzzy graph. In this paper, the necessary conditions for the union of two totally regular intuitionistic fuzzy graphs to be totally regular under some restrictions are obtained.

1. Introduction

Intuitionistic Fuzzy Graph theory was introduced by Atanassov in [1]. In [6] A. Nagoor Gani and S. Shajitha Begum introduced degree, order and size in intuitionistic fuzzy graph. In [10] Radha and Vijaya introduced the totally regular property of the composition of some fuzzy graphs. A. Nagoor Gani and H. Sheik Mujibur Rahman introduced the Total degree of a vertex in union, join Cartesian product and Composition of some intuitionistic fuzzy graphs in [7]. In this paper we introduce totally regular property of the Union of some intuitionistic fuzzy graph.

2. Preliminaries

Definition 2.1. An intuitionistic fuzzy graph (IFG) is of the form $G = \langle V, E \rangle$ where (i) $V = \{v_1, v_2, \ldots, v_n\}$ such that $\mu_1 : V \to [0, 1]$ and

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$\nu_1 : V \to [0, 1]$ denotes the degree of membership and non-membership of the element $v_i \in V$ respectively and $0 \leq \mu_1(v_i) + \nu_1(v_i) \leq 1$, for every $v_i \in V$.

(ii) $E \subseteq V \times V$ where $\mu_2 : V \times V \to [0, 1]$ and $\nu_2 : V \times V \to [0, 1]$ such that

$$\mu_2(v_i, v_j) \leq \min(\mu_1(v_i), \mu_1(v_j))$$

$$\nu_2(v_i, v_j) \leq \max(\nu_1(v_i), \nu_1(v_j))$$

and $0 \leq \mu_2(v_i, v_j) + \nu_2(v_i, v_j) \leq 1$, for every $(v_i, v_j) \in E$.

Here the triple $(v_i, \mu_{1i}, \nu_{1i})$ denotes the degree of membership and non-membership of the vertex v_i. The triple $(e_{ij}, \mu_{2ij}, \nu_{2ij})$ denotes the degree of membership and non-membership of the edge relation $e_{ij} = (v_i, v_j)$ on $V \times V$.

Definition 2.2. Let $G = \langle V, E \rangle$ be an IFG. Then the degree of a vertex v is defined by $d(v) = (d_\mu(v), d_\nu(v))$, where $d_\mu(v) = \sum_{u \neq v} \mu_2(v, u)$ and $d_\nu(v) = \sum_{u \neq v} \nu_2(v, u)$.

Definition 2.3. Let $G = \langle V, E \rangle$ be an IFG. If $(d_\mu(v), d_\nu(v)) = (k_1, k_2)$ for all $v \in V$ that is if each vertex has same membership degree k_1 and same non-membership degree k_2 then G is said to be a regular intuitionistic fuzzy graph.

Definition 2.4. Let $G = \langle V, E \rangle$ be an IFG. Then the total degree of a vertex $u \in v$ is defined by

$$td(u) = (td_\mu(u), td_\nu(u)) = \left(\sum_{u \neq v} \mu_2(u, v) + \mu_1(u), \sum_{u \neq v} \nu_2(u, v) + \nu_1(u) \right)$$

$$= (d_\mu(u) + \mu_1(u), d_\nu(u) + \nu_1(u)).$$

If each vertex of G has same membership total degree k_1 and same non membership total degree k_2, then said to be a totally regular intuitionistic fuzzy graph.

Definition 2.5. Let $G:(V, E)$ be an intuitionistic fuzzy graph. Then the minimum degree of G is $\delta(G) = (\delta_\mu(G), \delta_\nu(G))$, where $\delta_\mu(G) = \min\{d_\mu(v)/v \in V\}$ and $\delta_\nu(G) = \min\{d_\nu(v)/v \in V\}$.

Definition 2.6. Let $G:(V, E)$ be an intuitionistic fuzzy graph. Then the maximum degree of G is $\Delta(G) = (\Delta_\mu(G), \Delta_\nu(G))$, where $\Delta_\mu(G) = \max\{d_\mu(v)/v \in V\}$ and $\Delta_\nu(G) = \max\{d_\nu(v)/v \in V\}$.

Definition 2.7. Let $G:(V, E)$ be an intuitionistic fuzzy graph. Then G is an irregular intuitionistic fuzzy graph, if there is a vertex which is adjacent to vertices with distinct degrees.

Definition 2.8. The join of two intuitionistic fuzzy graphs G_1 and G_2 is an intuitionistic fuzzy graph $G = G_1 + G_2 = (V_1 \cup V_2, E_1 \cup E_2 \cup E')$ defined by

$$(\mu_1 + \mu_1')(v) = (\mu_1 \cup \mu_1')(v), \text{ if } v \in V_1 \cup V_2$$

$$(\nu_1 + \nu_1')(v) = (\nu_1 \cup \nu_1')(v), \text{ if } v \in V_1 \cup V_2$$

$$(\mu_2 + \mu_2')(v_i, v_j) = (\mu_2 \cup \mu_2')(v_i, v_j), \text{ if } v_i, v_j \in E_1 \cup E_2$$

$$= \mu_1(v_i) \wedge \mu_1'(v_j), \text{ if } v_i, v_j \in E'$$

$$(\nu_2 + \nu_2')(v_i, v_j) = (\nu_2 \cup \nu_2')(v_i, v_j), \text{ if } v_i, v_j \in E_1 \cup E_2$$

$$= \nu_1(v_i) \vee \nu_1'(v_j), \text{ if } v_i, v_j \in E'.$$

3. Total Degree of a Vertex in Join of Intuitionistic Fuzzy Graph

Let $G_1:(V, E)$ and $G_2:(V', E')$ be two intuitionistic fuzzy graphs with $V_1 \cap V_2 = \phi$.

(i) $$td_{\mu(G_1 \cup G_2)}(u) = \begin{cases} td_{\mu G_1}(u) + \sum_{uv \in E'} \mu_1(u) \wedge \mu_1'(v), \text{if for any } u \in V_1 \\ td_{\mu G_2}(u) + \sum_{uv \in E'} \mu_1(u) \wedge \mu_1'(v), \text{if for any } u \in V_2 \end{cases}$$

$$\text{(ii) } td_{\nu(G_1 \cup G_2)}(u) = \begin{cases} td_{\nu G_1}(u) + \sum_{uv \in E'} \nu_1(u) \vee \nu_1'(v), \text{ if for any } u \in V_1 \\ td_{\nu G_2}(u) + \sum_{uv \in E'} \nu_1(u) \vee \nu_1'(v), \text{ if for any } u \in V_2 \end{cases}.$$

4. Totally Regular Property of the Join of Intuitionistic Fuzzy Graphs

If G_1 and G_2 are totally regular intuitionistic fuzzy graphs, then $G_1 + G_2$ need not be a totally regular intuitionistic fuzzy graph. Let $\mu_1' \geq \mu_1$, $\nu_1' \geq \nu_1$. For example in figure 4.1, G_1 is (0.4, 0.4)-totally regular intuitionistic fuzzy graph and G_2 is (0.6, 0.6)-totally regular intuitionistic fuzzy graph. But $G_1 + G_2$ is not totally regular intuitionistic fuzzy graph.

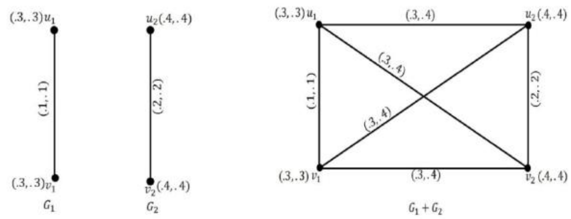


Figure 4.1

If $G_1 + G_2$ is a totally regular intuitionistic fuzzy graph, then G_1 and G_2 need not be totally regular intuitionistic fuzzy graphs.

In the following theorems, we obtain the necessary and sufficient conditions for the join of two intuitionistic fuzzy graphs to be totally regular in some particular cases.

Theorem 4.1. *Let G_1 and G_2 be totally regular intuitionistic fuzzy graphs of the same degree such that $\mu_1 \wedge \mu_1'$ and $\nu_1 \vee \nu_1'$ are constant functions. Then $G_1 + G_2$ is totally regular intuitionistic fuzzy graph if and only if $p_1 = p_2$.*

Proof. Let G_1 and G_2 be k-totally regular intuitionistic fuzzy graphs.

Let $\mu_1(u) \wedge \mu_1'(v) = c_1$ for all $u \in V_1$ and $v \in V_2$ and $\nu_1(u) \vee \nu_1'(v) = c_2$ for all $u \in V_1$ and $v \in V_2$, where c_1 and c_2 are constants.

For any $u \in V_1$,

$$td_{\mu(G_1+G_2)}(u) = td_{\mu(G_1)}(u) + \sum_{uv \in E'} \mu_1(u) \wedge \mu'_1(v)$$

$$= td_{\mu(G_1)}(u) + \sum_{v \in V_2} c_1$$

$$= k + c_1 p_2$$

$$td_{\nu(G_1+G_2)}(u) = td_{\nu(G_1)}(u) + \sum_{uv \in E'} \nu_1(u) \vee \nu'_1(v)$$

$$= td_{\nu(G_1)}(u) + \sum_{v \in V_2} c_2$$

$$= k + c_2 p_2.$$

For any $u \in V_2$,

$$td_{\mu(G_1+G_2)}(u) = td_{\mu(G_2)}(u) + \sum_{uv \in E'} \mu_1(u) \wedge \mu'_1(v)$$

$$= td_{\mu(G_2)}(u) + \sum_{v \in V_1} c_1$$

$$= k + c_1 p_1$$

$$td_{\nu(G_1+G_2)}(u) = td_{\nu(G_2)}(u) + \sum_{uv \in E'} \nu_1(u) \vee \nu'_1(v)$$

$$= td_{\nu(G_2)}(u) + \sum_{v \in V_1} c_2$$

$$= k + c_2 p_1.$$

Now we have $G_1 + G_2$ is a totally regular intuitionistic fuzzy graph

$$\Leftrightarrow k + c_1 p_2 = k + c_1 p_1 \Leftrightarrow p_2 = p_1$$

$$\Leftrightarrow k + c_2 p_1 = k + c_2 p_2 \Leftrightarrow p_2 = p_1.$$

Corollary 4.2. *Let* $G_2 : (\mu_1, \mu_2)$ *and* $G_2 : (\mu'_1, \mu'_2)$ *be two k-totally regular intuitionistic fuzzy graphs such that* $\mu_1 \geq \mu'_1$ *(or* $\mu'_1 \geq \mu_1$*),* $\nu_1 \geq \nu'_1$ *and* μ'_1 *(or* μ_1*),* ν'_1 *(or* ν_1*) are constant functions. Then* $G_1 + G_2$ *is a totally regular intuitionistic fuzzy graph if and only if* $p_2 = p_1$.

Proof. If $\mu_1 \geq \mu'_1$ and μ'_1 is a constant function, then $\mu_1 \wedge \mu'_1 = \mu'_1$ is a constant function. If $\mu'_1 \geq \mu_1$ and μ_1 is a constant function, then $\mu_1 \wedge \mu'_1 = \mu_1$ is a constant function.

If $\nu_1 \geq \nu'_1$ and ν'_1 is a constant function, then $\nu_1 \vee \nu'_1 = \nu'_1$ is a constant function. If $\nu'_1 \geq \nu_1$ and ν_1 is a constant function, then $\nu_1 \vee \nu_1 = \nu_1$ is a constant function.

Theorem 4.3. *Let* G_1 *and* G_2 *be two intuitionistic fuzzy graphs such that* $p_1 = p_2$, $\mu_1 \wedge \mu'_1$ *and* $\nu_1 \vee \nu'_1$ *are constant functions. Then* $G_1 + G_2$ *is totally regular intuitionistic fuzzy graph if and only if* G_1 *and* G_2 *are both totally regular intuitionistic fuzzy graphs of the same degree.*

Proof. Let G_1 *and* G_2 be two intuitionistic fuzzy graphs such that $p_1 = p_2 = p(say)$ and $\mu_1(u) \wedge \mu'_1(v) = c_1$, for all $u \in V_1, v \in V_2$ and $\nu_1(u) \vee \nu'_1(v) = c_2$, for all $u \in V_1$, $v \in V_2$, where c_1, c_2 are constants.

For any $u \in V_1$,

$$td_{\mu(G_1+G_2)}(u) = td_{\mu(G_1)}(u) + \sum_{uv \in E'} \mu_1(u) \wedge \mu'_1(v)$$

$$= td_{\mu(G_1)}(u) + \sum_{v \in V_2} c_1$$

$$= td_{\mu(G_1)}(u) + c_1 p$$

$$td_{\nu(G_1+G_2)}(u) = td_{\nu(G_1)}(u) + \sum_{uv \in E'} \nu_1(u) \vee \nu'_1(v)$$

$$= td_{\nu(G_1)}(u) + \sum_{v \in V_2} c_2$$

$$= td_{\nu(G_1)}(u) + c_2 p.$$

For any $w \in V_2$,

$$\begin{aligned} td_{\mu(G_1+G_2)}(w) &= td_{\mu(G_2)}(w) + \sum_{uv \in E'} \mu_1(u) \wedge \mu_1'(v) \\ &= td_{\mu(G_2)}(w) + \sum_{v \in V_1} c_1 \\ &= td_{\mu(G_2)}(w) + c_1 p \\ td_{\nu(G_1+G_2)}(w) &= td_{\nu(G_2)}(w) + \sum_{uv \in E'} \nu_1(u) \vee \nu_1'(v) \\ &= td_{\nu(G_2)}(w) + \sum_{v \in V_1} c_2 \\ &= td_{\nu(G_2)}(w) + c_2 p. \end{aligned}$$

Now we have $G_1 + G_2$ is a totally regular intuitionistic fuzzy graph

$\Leftrightarrow td_{\mu(G_1)}(u) + c_1 p = td_{\mu(G_2)}(w) + c_1 p$

$\Leftrightarrow td_{\mu(G_1)}(u) = td_{\mu(G_2)}(w)$, where $u \in V_1$ and $w \in V_2$ are arbitrary.

$\Leftrightarrow td_{\nu(G_1)}(u) + c_2 p = td_{\nu(G_2)}(w) + c_2 p$

$\Leftrightarrow td_{\nu(G_1)}(u) = td_{\nu(G_2)}(w)$, where $u \in V_1$ and $w \in V_2$ are arbitrary.

Hence, $G_1 + G_2$ is a totally regular fuzzy graph if and only if G_1 and G_2 are both totally regular intuitionistic fuzzy graphs of the same degree.

Corollary 4.4. *Let $G_1 : (\mu_1, \mu_2)$ and $G_2 : (\mu_1', \mu_2')$ be two intuitionistic fuzzy graphs such that $p_2 = p_1$, $\mu_1 \geq \mu_1'$ (or $\mu_1' \geq \mu_1$), $\nu_1 \geq \nu_1'$ (or $\nu_1' \geq \nu_1$) and μ_1' (or μ_1), ν_1' (or ν_1) are constant functions. Then $G_1 + G_2$ is a totally regular intuitionistic fuzzy graph if and only if G_1 and G_2 are both totally regular intuitionistic fuzzy graphs of the same degree.*

Proof. Proof is similar to the above theorem 4.3.

Theorem 4.5. *Let $G_1 : (\mu_1, \mu_2)$ and $G_2 : (\mu_1', \mu_2')$ be two totally regular intuitionistic fuzzy graphs such that $\mu_1 \geq \mu_1'$ (or $\mu_1' \geq \mu_1$), $\nu_1 \geq \nu_1'$ (or*

$\nu_1' \geq \nu_1$). *If* $G_1 + G_2$ *is a totally regular intuitionistic fuzzy graph, then* μ_1' (*or* μ_1), ν_1' (*or* ν_1) *are constant functions*.

Proof. Let $\mu_1 \geq \mu_1', \nu_1 \geq \nu_1'$ and let G_i be a k_i-totally regular intuitionistic fuzzy graph, $i = 1, 2, 3, 4$.

For any $u \in V_1$,

$$td_{\mu(G_1+G_2)}(u) = td_{\mu(G_1)}(u) + \sum_{uv \in E'} \mu_1(u) \wedge \mu_1'(v)$$

$$= td_{\mu(G_1)}(u) + \sum_{v \in V_2} \mu_1'(v)$$

$$= k_1 + O_\mu(G_2)$$

$$td_{\nu(G_1+G_2)}(u) = td_{\nu(G_1)}(u) + \sum_{uv \in E'} \nu_1(u) \vee \nu_1'(v)$$

$$= td_{\nu(G_1)}(u) + \sum_{v \in V_2} \nu_1'(v)$$

$$= k_2 + O_\nu(G_2).$$

For any $u \in V_2$,

$$td_{\mu(G_1+G_2)}(u) = td_{\mu(G_2)}(u) + \sum_{uv \in E'} \mu_1(v) \wedge \mu_1'(u)$$

$$= td_{\mu(G_2)}(u) + \sum_{v \in V_2} \mu_1'(u)$$

$$= k_3 + p_1 \mu_1'(u)$$

$$td_{\nu(G_1+G_2)}(u) = td_{\nu(G_2)}(u) + \sum_{uv \in E'} \nu_1(v) \wedge \nu_1(u)$$

$$= td_{\nu(G_2)}(u) + \sum_{v \in V_2} \nu_1'(u)$$

$$= k_4 + p_2 \nu_1'(u).$$

Since $G_1 + G_2$ is a totally regular intuitionistic fuzzy graph then $k_1 + O_\mu(G_2) = k_3 + p_2\mu_1'(u)$, for any $u \in V_2$

$\Rightarrow k_1 - k_3 = p_1\mu_1'(u) - O_\mu(G_2)$, for any $u \in V_2$.

For any $u, v \in V_2$, $p_1\mu_1'(u) - O_\mu(G_2) = k_1 - k_3 = p_1\mu_1'(v) - O_\mu(G_2)$

$\Rightarrow p_1\mu_1'(u) = p_1\mu_1'(v)$

$\Rightarrow \mu_1'(u) = \mu_1'(v)$. Similarly

$k_2 + O_\nu(G_2) = k_4 + p_2\nu_1'(u)$, for any $u \in V_2$

$\Rightarrow k_2 - k_4 = p_1\nu_1'(u) - O_\nu(G_2)$, for any $u \in V_2$.

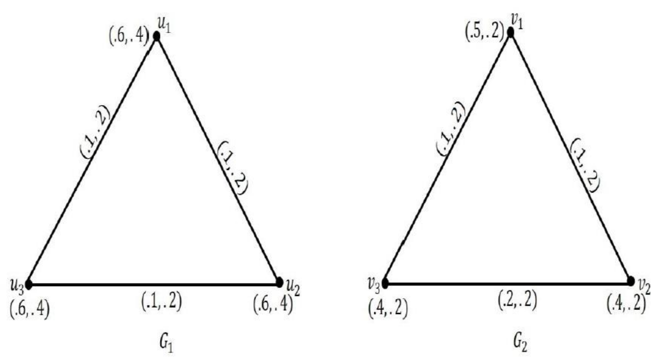
For any $u, v \in V_2$, $p_1\nu_1'(u) - O_\nu(G_2) = k_2 - k_4 = p_1\nu_1'(v) - O_\nu(G_2)$

$\Rightarrow p_1\nu_1'(u) = p_1\nu_1'(v)$

$\Rightarrow \nu_1'(u) = \nu_1(v)$.

Hence, μ_1' and ν_1' are constant functions.

Example 4.6. The converse of the above theorem need not be true. For example, in figure 4.2, G_1 is (0.8, 0.8)-totally regular intuitionistic fuzzy graph and G_2 is (0.7, 0.6)-totally regular intuitionistic fuzzy graph such that $\mu_1' \geq \mu_1$, $\nu_1' \geq \nu_1$ and μ_1, ν_1 are constant functions. But $G_1 + G_2$ is not a totally regular intuitionistic fuzzy graph.



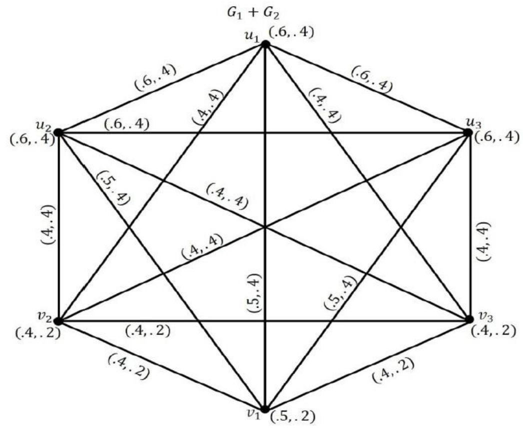


Figure 4.2.

Theorem 4.7. *Let* $G_1 : (\mu_1, \mu_2)$ *and* $G_2 : (\mu_1', \mu_2')$ *be two intuitionistic fuzzy graphs of degrees* k_i, *(where* $i = 1, 2, 3, 4$*) such that* $\mu_1 \wedge \mu_1'$ *and* $\nu_1 \vee \nu_1'$ *are constant functions. Then* $G_1 + G_2$ *is a totally regular intuitionistic fuzzy graph if and only if*

(i) $k_1 - k_3 = c_1(p_1 - p_2)$, *where* c_1 *is the constant value of* $\mu_1 \wedge \mu_1'$

(ii) $k_2 - k_4 = c_2(p_1 - p_2)$, *where* c_2 *is the constant value of* $\nu_1 \vee \nu_1'$.

Proof. For any $u \in V_1$,

$$td_{\mu(G_1+G_2)}(u) = td_{\mu(G_1)}(u) + \sum_{uv \in E'} \mu_1(u) \wedge \mu_1'(v)$$

$$= td_{\mu(G_1)}(u) + \sum_{v \in V_2} c_1$$

$$= k_1 + c_1 p_2$$

$$td_{\nu(G_1+G_2)}(u) = td_{\nu(G_1)}(u) + \sum_{uv \in E'} \nu_1(u) \vee \nu_1'(v)$$

$$= td_{\nu(G_1)}(u) + \sum_{v \in V_2} c_2$$

$$= k_2 + c_2 p_2.$$

For any $u \in V_2$,

$$td_{\mu(G_1+G_2)}(u) = td_{\mu(G_2)}(u) + \sum_{uv \in E'} \mu_1(v) \wedge \mu_1'(u)$$

$$= td_{\mu(G_2)}(u) + \sum_{v \in V_2} c_1$$

$$= k_3 + c_1 p_1$$

$$td_{\nu(G_1+G_2)}(u) = td_{\nu(G_2)}(u) + \sum_{uv \in E'} \nu_1(u) \wedge \nu_1'(v)$$

$$= td_{\nu(G_2)}(u) + \sum_{v \in V_2} c_2$$

$$= k_4 + c_2 p_1.$$

Hence, $G_1 + G_2$ is a totally regular intuitionistic fuzzy graph

$$\Leftrightarrow k_1 + c_1 p_2 = k_3 + c_1 p_1$$

$$\Leftrightarrow k_1 - k_3 = c_1 p_1 - c_1 p_2$$

$$\Leftrightarrow k_1 - k_3 = c_1(p_1 - p_2).$$

Similarly,

$$\Leftrightarrow k_2 + c_2 p_2 = k_4 + c_2 p_1$$

$$\Leftrightarrow k_2 - k_4 = c_2 p_1 - c_2 p_2$$

$$\Leftrightarrow k_2 - k_4 = c_2(p_1 - p_2).$$

Corollary 4.8. Let $G_1 : (\mu_1, \mu_2)$ *and* $G_2 : (\mu_1', \mu_2')$ *be two intuitionistic fuzzy graphs such that* $\mu_1 \geq \mu_1'$ *(or* $\mu_1' \geq \mu_1$*),* $\nu_1 \geq \nu_1'$ *(or* $\nu_1' \geq \nu_1$*) and* μ_1' *(or* μ_1*),* ν_1' *(or* ν_1*) are constant functions. Then* $G_1 + G_2$ *is a totally regular intuitionistic fuzzy graph if and only if*

(i) $k_1 - k_3 = c_1(p_1 - p_2)$, *where* c_1 *is the constant value of* μ_1' *(or* μ_1*)*

(ii) $k_2 - k_4 = c_2(p_1 - p_2)$, *where* c_2 *is the constant value of* ν_1' *(or* ν_1*).*

5. Conclusion

In this paper we have showed that the Join of two totally regular intuitionistic fuzzy graphs need not be a totally regular intuitionistic fuzzy graph. We have also obtained the conditions for the Join of two intuitionistic fuzzy graphs to be totally regular in some particular cases.

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