International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-4, November 2019

Degree of a Vertex in Max-Product of Intuitionistic Fuzzy Graph

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Abstract: ***Graph theory has applications in many areas of computer science, including data mining, image segmentation, clustering and networking. Product on graphs has a wide range of application in networking system, automata theory, game theory and structural mechanics. In many cases, some aspects of a graph-theoretic problem may be uncertain. Intuitionistic fuzzy models provide more compatible to the system compared to the fuzzy models. An intuitionistic fuzzy graph can be derived from two given intuitionistic fuzzy graphs using max-product. In this paper, we studied the degree of vertex in intuitionistic fuzzy graph by the max-product of two given intuitionistic fuzzy graph. Also find the necessary and sufficient condition for max-product of two intuitionistic fuzzy graphs to be regular.***

Keywords: ***Intuitionistic fuzzy graph (IFG), Max-Product, Regular Intuitionistic fuzzy graph.***

I. INTRODUCTION

In 1965, Zadeh [30] represented the uncertainty as fuzzy subset of sets. Since then, the theory of fuzzy sets has become a strong area of research in different disciplines including medical and life sciences, management sciences, social sciences, engineering, statistics, artificial intelligence, signal processing, graph theory, multi-agent systems, pattern recognition, robotics, computer networks, expert systems, decision-making, automata theory, etc. The concept of intuitionistic fuzzy set was introduced by Atanassov [2]. Shannon and Atanassov [5] introduced the notion of intuitionistic fuzzy graphs in 1994. Parvathi and Karunambigai [6] defined the intuitionistic fuzzy graph as a special case of intuitionistic fuzzy graphs introduced by Atanassov and Shannon [2]. Akram and Davvaz [1] studied some operations on strong intuitionistic fuzzy graphs. Yahya Mohamed and Mohamed Ali [6, 7, 8] introduced the max-product and modular product on intuitionistic fuzzy graphs and they defined the complement of modular product of two intuitionistic fuzzy graph. Some recent works in intuitionistic fuzzy graph and interval-valued Pythagorean fuzzy graph can be found in [9, 10, 11, 12]. In this paper, we have studied the degree of vertex in intuitionistic fuzzy graph by the max-product of two given intuitionistic fuzzy graph. Some regularity conditions for max product are stated and proved.

Manuscript published on November 30, 2019.
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II. PRELIMINARIES

Throughout this paper, assume that G^* is a crisp graph and G is an intuitionistic fuzzy graph.

Definition 2.1

An *intuitionistic fuzzy graph* is of the form $G = ((\sigma_1, \sigma_2), (\mu_1, \mu_2))$ on $G^* = (V, E)$, where

1. $V = \{x_1, x_2, \ldots, x_n\}$ such that $\sigma_1: V \to [0,1]$ and $\sigma_2 : V \to [0,1]$ denote the degree of membership and non-membership of the element $x_i \in V$ respectively, such that $\sigma_1(x_i) + \sigma_2(x_i) \leq 1$ for all $x_i \in V$.
2. $E \subseteq V \times V$ where $\mu_1: E \to [0,1]$ and $\mu_2 : E \to [0,1]$ are defined by $\mu_1(x_i, x_j) \leq \sigma_1(x_i) \wedge \sigma_1(x_j)$ and $\mu_2(x_i, x_j) \leq \sigma_2(x_i) \vee \sigma_2(x_j)$ such that $\mu_1(x_i, x_j) + \mu_2(x_i, x_j) \leq 1$, $\forall (x_i, x_j) \in E$.

Definition 2.2

An intuitionistic fuzzy graph $G = ((\sigma_1, \sigma_2), (\mu_1, \mu_2))$ is called *strong* intuitionistic fuzzy graph if

$$\mu_1(x_i, x_j) = \sigma_1(x_i) \wedge \sigma_1(x_j) \text{ and}$$
$$\mu_2(x_i, x_j) = \sigma_2(x_i) \vee \sigma_2(x_j), \quad \forall\, (x_i, x_j) \in E, i \neq j.$$

Definition 2.3

An intuitionistic fuzzy graph $G = ((\sigma_1, \sigma_2), (\mu_1, \mu_2))$ is called *complete* intuitionistic fuzzy graph if

$$\mu_1(x_i, x_j) = \sigma_1(x_i) \wedge \sigma_1(x_j) \text{ and}$$
$$\mu_2(x_i, x_j) = \sigma_2(x_i) \vee \sigma_2(x_j), \forall\, x_i, x_j \in V,\, i \neq j.$$

Definition 2.4

Let $G = ((\sigma_1, \sigma_2), (\mu_1, \mu_2))$ be an intuitionistic fuzzy graph, then the order of G is defined to be $O(G) = \left(O_{\sigma_1}(G), O_{\sigma_2}(G)\right)$ where $O_{\sigma_1}(G) = \sum_{x \in V} \sigma_1(x)$ and $O_{\sigma_2}(G) = \sum_{x \in V} \sigma_2(x)$.

Definition 2.5

Let $G = ((\sigma_1, \sigma_2), (\mu_1, \mu_2))$ be an intuitionistic fuzzy graph, then the size of G is defined to be $S(G) = \left(S_{\mu_1}(G), S_{\mu_2}(G)\right)$

where $S_{\mu_1}(G) = \sum_{xy\in E} \mu_1(xy)$ and $S_{\mu_2}(G) = \sum_{xy\in E} \mu_2(xy)$.

Definition 2.6

The complement of an intuitionistic fuzzy graph $G = (V, E)$ is an intuitionistic fuzzy graph $\bar{G} = (\overline{(\sigma_1,\sigma_2)}, \overline{(\mu_1,\mu_2)})$, where $\overline{(\sigma_1,\sigma_2)} = (\sigma_1,\sigma_2)$ and
$\bar{\mu}_1(xy) = \sigma_1(x) \wedge \sigma_2(y) - \mu_1(xy)$ and
$\bar{\mu}_2(xy) = \sigma_1(x) \vee \sigma_2(y) - \mu_2(xy), \forall xy \in E$.

Definition 2.7

Let $G = ((\sigma_1,\sigma_2),(\mu_1,\mu_2))$ be an intuitionistic fuzzy graph. The degree of a vertex x in G is denoted by $d_G(x) = (d_1^G(x), d_2^G(x))$ and defined by $d_1^G(u) = \sum_{x\neq y} \mu_1^G(x,y) = \sum_{(x,y)\in E} \mu_1^G(x,y)$ and $d_2^G(u) = \sum_{x\neq y} \mu_2^G(x,y) = \sum_{(x,y)\in E} \mu_2^G(x,y)$.

Definition 2.8

Let $G_1 : \left((\sigma_1^{G_1},\sigma_2^{G_1}),(\mu_1^{G_1},\mu_2^{G_1})\right)$ and $G_2 : ((\sigma_1^{G_2},\sigma_2^{G_2}), (\mu_1^{G_2},\mu_2^{G_2}))$ be two intuitionistic fuzzy graphs. The max-product of two intuitionistic fuzzy graph G_1 and G_2 is denoted by $G_1 \times_m G_2 = (V_1 \times_m V_2, E_1 \times_m E_2)$, $E_1 \times_m E_2 = \{(u_1,v_1)(u_1,v_2) \,/\, u_1 = u_2, v_1v_2 \in E_2 \ or \ v_1 = v_2, u_1u_2 \in E_1\}$ by $\sigma_1^{G_1\times_m G_2}(u_1,v_1) = \sigma_1^{G_1}(u_1) \vee \sigma_1^{G_2}(v_1)$, $\sigma_2^{G_1\times_m G_2}(u_1,v_1) = \sigma_1^{G_1}(u_1) \wedge \sigma_1^{G_2}(v_1)$, for all $(u_1,v_1) \in V_1 \times V_2$ and

$$\mu_1^{G_1\times_m G_2}((u_1,v_1)(u_2,v_2)) = \begin{cases} \sigma_1^{G_1}(u_1) \vee \mu_1^{G_2}(v_1v_2) & \text{if} \quad u_1 = u_2, v_1v_2 \in E_2 \\ \mu_1^{G_1}(u_1u_2) \vee \sigma_1^{G_2}(v_1) & \text{if} \quad v_1 = v_2, u_1u_2 \in E_1 \end{cases}$$

$$\mu_2^{G_1\times_m G_2}((u_1,v_1)(u_2,v_2)) = \begin{cases} \sigma_2^{G_1}(u_1) \wedge \mu_2^{G_2}(v_1v_2) & \text{if} \quad u_1 = u_2, v_1v_2 \in E_2 \\ \mu_2^{G_1}(u_1u_2) \wedge \sigma_2^{G_2}(v_1) & \text{if} \quad v_1 = v_2, u_1u_2 \in E_1 \end{cases}$$

Example 2.9

Let $G_1^* = (V_1, E_1)$ and $G_2^* = (V_2, E_2)$ be two crisp graphs such that $V_1 = \{u_1,u_2,u_3\}, V_2 = \{v_1,v_2\}$,

$E_1 = \{u_1u_3, u_2u_3\}, E_2 = \{v_1v_2\}$. Consider two intuitionistic fuzzy graphs $G_1 = \left((\sigma_1^{G_1},\sigma_2^{G_1}),(\mu_1^{G_1},\mu_2^{G_1})\right)$ and $G_2 = \left((\sigma_1^{G_2},\sigma_2^{G_2}),(\mu_1^{G_2},\mu_2^{G_2})\right)$ and $G_1 \times_m G_2$ as follows:

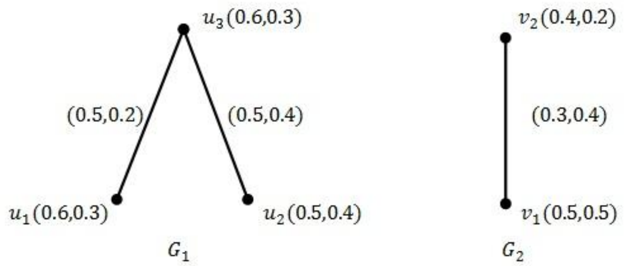

Figure - 1

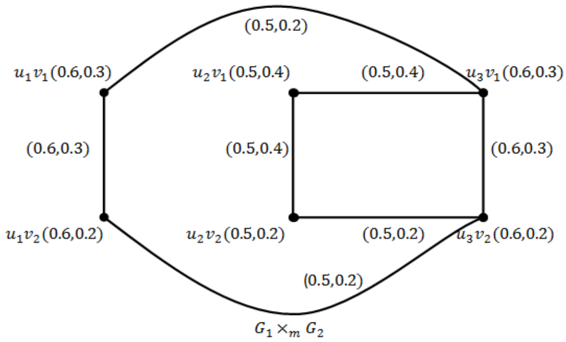

Figure - 2

III. DEGREE OF A VERTEX IN MAX-PRODUCT OF INTUITIONISTIC FUZZY GRAPH

For any vertex $(u_1,u_2) \in V_1 \times V_2$. The degree of a vertex in $G_1 \times_m G_2$ is defined as
$d^{G_1\times G_2}(u_1,u_2) = \left(d_1^{G_1\times G_2}(u_1,u_2), d_2^{G_1\times G_2}(u_1,u_2)\right)$, where

$$d_1^{G_1\times_m G_2}(u_1,u_2) = \sum_{(u_1,u_2)(v_1,v_2)\,\in\, E_1\times E_2} \mu_1^{G_1\times G_2}((u_1,u_2)(v_1,v_2))$$
$$= \sum_{u_1=v_1,u_2v_2\in E_2} \sigma_1^{G_1}(u_1) \vee \mu_1^{G_2}(u_2v_2) + \sum_{u_2=v_2,u_1v_1\in E_1} \mu_1^{G_1}(u_1v_1) \vee \sigma_1^{G_2}(u_2),$$

$$d_2^{G_1\times_m G_2}(u_1,u_2) = \sum_{(u_1,u_2)(v_1,v_2)\,\in\, E_1\times E_2} \mu_2^{G_1\times G_2}((u_1,u_2)(v_1,v_2))$$
$$= \sum_{u_1=v_1,u_2v_2\in E_2} \sigma_2^{G_1}(u_1) \wedge \mu_2^{G_2}(u_2v_2) + \sum_{u_2=v_2,u_1v_1\in E_1} \mu_2^{G_1}(u_1v_1) \wedge \sigma_2^{G_2}(u_2).$$

IV. REGULARITY CONDITION ON $G_1 \times_m G_2$

In this section, we derived the necessary and sufficient of conditions for the max product of two given intuitionistic fuzzy graph $G_1 \times_m G_2$ to be regular.

Theorem 4.1

Let $G_1 : \left((\sigma_1^{G_1},\sigma_2^{G_1}),(\mu_1^{G_1},\mu_2^{G_1})\right)$ and $G_2 : \left((\sigma_1^{G_2},\sigma_2^{G_2}),(\mu_1^{G_2},\mu_2^{G_2})\right)$ be two intuitionistic fuzzy graphs with underlying crisp graphs G_1^* and G_2^* are regular. If $\sigma_1^{G_1} \le \mu_1^{G_2}$, $\sigma_2^{G_1} \ge \mu_2^{G_2}$; $\sigma_1^{G_2} \ge \mu_1^{G_1}, \sigma_2^{G_2} \le \mu_2^{G_1}$ and $\sigma_1^{G_2}, \sigma_2^{G_2}$ are constant functions, then $G_1 \times_m G_2$ is regular if and only if G_2 is regular intuitionistic fuzzy graph.

Retrieval Number: C6411098319/2019©BEIESP
DOI:10.35940/ijrte.C6411.118419
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Proof:

Let $G_1:\left((\sigma_1^{G_1},\sigma_2^{G_1}),(\mu_1^{G_1},\mu_2^{G_1})\right)$ and $G_2:\left((\sigma_1^{G_2},\sigma_2^{G_2}),(\mu_1^{G_2},\mu_2^{G_2})\right)$ be two intuitionistic fuzzy graphs with underlying crisp graphs G_1^* and G_2^* are regular with $d^{G_1^*}=r_1$; $d^{G_2^*}=r_2$ and $\sigma_1^{G_1}\le\mu_1^{G_2}$, $\sigma_2^{G_1}\ge\mu_2^{G_2}$; $\sigma_1^{G_2}\ge\mu_1^{G_1},\sigma_2^{G_2}\le\mu_2^{G_1}$ and $\sigma_1^{G_2},\sigma_2^{G_2}$ are constant functions of values k_1 and k_2 respectively.

Assume that G_2 is (p,q) - regular intuitionistic fuzzy graph.

Then, the degree of any vertex in max-product of intuitionistic fuzzy graph is given by

$d^{G_1\times G_2}(u_1,u_2)=\left(d_1^{G_1\times G_2}(u_1,u_2),d_2^{G_1\times G_2}(u_1,u_2)\right)$, where

$$d_1^{G_1\times_m G_2}(u_1,u_2)=\sum_{(u_1,u_2),(v_1,v_2)\in E_1\times E_2}\mu_1^{G_1\times G_2}\left((u_1,v_1)(u_2,v_2)\right)$$

$$=\sum_{u_1=v_1,u_2v_2\in E_2}\sigma_1^{G_1}(u_1)\vee\mu_1^{G_2}(u_2v_2)+\sum_{u_2=v_2,u_1v_1\in E_1}\mu_1^{G_1}(u_1v_1)\vee\sigma_1^{G_2}(u_2)$$

$$=\sum_{u_1=v_1,u_2v_2\in E_2}\mu_1^{G_2}(u_2v_2)+\sum_{u_2=v_2,u_1v_1\in E_1}\sigma_1^{G_2}(u_1)$$

$$=d_1^{G_2}(u_2)+d^{G_1^*}(u_1)\,\sigma_1^{G_2}(u_1)$$

$$=p+r_1k_1$$

and

$$d_2^{G_1\times_m G_2}(u_1,u_2)=\sum_{(u_1,u_2)(v_1,v_2)\in E_1\times E_2}\mu_2^{G_1\times G_2}\left((u_1,v_1)(u_2,v_2)\right)$$

$$=\sum_{u_1=v_1,u_2v_2\in E_2}\sigma_2^{G_1}(u_1)\wedge\mu_2^{G_2}(u_2v_2)+\sum_{u_2=v_2,u_1v_1\in E_1}\mu_2^{G_1}(u_1v_1)\wedge\sigma_2^{G_2}(u_2)$$

$$=\sum_{u_1=v_1,u_2v_2\in E_2}\mu_2^{G_2}(u_2v_2)+\sum_{u_2=v_2,u_1v_1\in E_1}\sigma_2^{G_2}(u_1)$$

$$=d_2^{G_2}(u_2)+d^{G_1^*}(u_1)\,\sigma_2^{G_2}(u_1)$$

$$=q+r_1k_2$$

$d^{G_1\times G_2}(u_1,u_2)=(p+rk_1,q+rk_2)$ is constant for all vertices $(u_1,u_2)\in V_1\times V_2$.

Hence $G_1\times_m G_2$ is a regular intuitionistic fuzzy graph.

Conversely,

Let $G_1\times_m G_2$ is a regular intuitionistic fuzzy graph.

Then, for any two vertices (u_1,u_2) and (v_1,v_2) in $V_1\times V_2$.

$$d_1^{G_1\times_m G_2}(u_1,u_2)=d_1^{G_1\times_m G_2}(v_1,v_2)$$

$$d_1^{G_2}(u_2)+d^{G_1^*}(u_1)\,\sigma_1^{G_2}(u_1)=d_1^{G_2}(v_2)+d^{G_1^*}(v_1)\,\sigma_1^{G_2}(v_1)$$

$$r_1k_1+d_1^{G_2}(u_2)=r_1k_1+d_1^{G_2}(v_2)$$

$$d_1^{G_2}(u_2)=d_1^{G_2}(v_2)$$

Similarly,

$$d_2^{G_1\times_m G_2}(u_1,u_2)=d_2^{G_1\times_m G_2}(v_1,v_2)$$

$$d_2^{G_2}(u_2)+d^{G_2^*}(u_1)\,\sigma_2^{G_2}(u_1)=d_2^{G_2}(v_2)+d^{G_2^*}(v_1)\,\sigma_2^{G_2}(v_1)$$

$$r_1k_2+d_2^{G_2}(u_2)=r_1k_2+d_2^{G_2}(v_2)$$

$$d_2^{G_2}(u_2)=d_2^{G_2}(v_2)$$

This condition is true for all vertices $(u_1,u_2)\in V_1\times V_2$.

Hence G_2 is a regular intuitionistic fuzzy graph.

Theorem 4.2

Let $G_1:\left((\sigma_1^{G_1},\sigma_2^{G_1}),(\mu_1^{G_1},\mu_2^{G_1})\right)$ and $G_2:\left((\sigma_1^{G_2},\sigma_2^{G_2}),(\mu_1^{G_2},\mu_2^{G_2})\right)$ be two intuitionistic fuzzy graphs with underlying crisp graphs G_1^* and G_2^* are regular. If $\sigma_1^{G_1}\le\mu_1^{G_2}$, $\sigma_2^{G_1}\ge\mu_2^{G_2}$; $\sigma_1^{G_2}\ge\mu_1^{G_1},\sigma_2^{G_2}\le\mu_2^{G_1}$ and $\sigma_1^{G_2},\sigma_2^{G_2}$ are constant functions, then $G_1\times_m G_2$ is regular if and only if $\sigma_1^{G_1}$ and $\sigma_2^{G_1}$ are constant functions.

Proof:

Let $G_1:\left((\sigma_1^{G_1},\sigma_2^{G_1}),(\mu_1^{G_1},\mu_2^{G_1})\right)$ and $G_2:\left((\sigma_1^{G_2},\sigma_2^{G_2}),(\mu_1^{G_2},\mu_2^{G_2})\right)$ be two intuitionistic fuzzy graphs with underlying crisp graphs G_1^* and G_2^* are r-regular and $\sigma_1^{G_1}\le\mu_1^{G_2}$, $\sigma_2^{G_1}\ge\mu_2^{G_2}$; $\sigma_1^{G_2}\ge\mu_1^{G_1},\sigma_2^{G_2}\le\mu_2^{G_1}$ and $\sigma_1^{G_2},\sigma_2^{G_2}$ are constant functions of values k_1 and k_2 respectively.

Now assume that $\sigma_1^{G_1}$ and $\sigma_2^{G_1}$ are constant functions of values k_3 and k_4 respectively.

Then the degree of any vertex in max-product of two intuitionistic fuzzy graphs is given by

$$d_1^{G_1\times G_2}(u_1,u_2)=\sum_{(u_1,u_2)(v_1,v_2)\in E_1\times E_2}\mu_1^{G_1\times G_2}\left((u_1,v_1)(u_2,v_2)\right)$$

$$=\sum_{u_1=v_1,u_2v_2\in E_2}\sigma_1^{G_1}(u_1)\vee\mu_1^{G_2}(u_2v_2)+\sum_{u_2=v_2,u_1v_1\in E_1}\mu_1^{G_1}(u_1v_1)\vee\sigma_1^{G_2}(u_2)$$

$$=\sum_{u_1=v_1,u_2v_2\in E_2}\sigma_1^{G_1}(u_1)+\sum_{u_2=v_2,u_1v_1\in E_1}\sigma_1^{G_2}(u_1)$$

$$=d^{G_2^*}(u_2)\,\sigma_1^{G_1}(u_1)+d^{G_1^*}(u_1)\,\sigma_1^{G_2}(u_1)$$

$$=r_2k_3+r_1k_1$$

$$d_2^{G_1\times G_2}(u_1,u_2)=\sum_{(u_1,u_2)(v_1,v_2)\in E_1\times E_2}\mu_2^{G_1\times G_2}\left((u_1,v_1)(u_2,v_2)\right)$$

$$=\sum_{u_1=v_1,u_2v_2\in E_2}\sigma_2^{G_1}(u_1)\wedge\mu_2^{G_2}(u_2v_2)+\sum_{u_2=v_2,u_1v_1\in E_1}\mu_2^{G_1}(u_1v_1)\wedge\sigma_2^{G_2}(u_2)$$

$$= \sum_{u_1=v_1, u_2v_2\in E_2} \sigma_2^{G_1}(u_1) + \sum_{u_2=v_2, u_1v_1\in E_1} \sigma_2^{G_2}(u_1)$$
$$= d^{G_2^*}(u_2)\,\sigma_2^{G_1}(u_1) + d^{G_1^*}(u_1)\,\sigma_2^{G_2}(u_1)$$
$$= rk_4 + rk_2$$

This is true for all vertices in $V_1 \times V_2$. Hence $G_1 \times_m G_2$ is regular intuitionistic fuzzy graph.

Conversely, assume that $G_1 \times_m G_2$ is a regular intuitionistic fuzzy graph. Then for any two vertices (u_1, u_2) and (v_1, v_2) in $V_1 \times V_2$.

$$d_1^{G_1\times_m G_2}(u_1, u_2) = d_1^{G_1\times_m G_2}(v_1, v_2)$$
$$d^{G_2^*}(u_2)\,\sigma_1^{G_1}(u_1) + d^{G_1^*}(u_1)\,\sigma_1^{G_2}(u_1)$$
$$= d^{G_2^*}(v_2)\,\sigma_1^{G_1}(v_1) + d^{G_1^*}(v_1)\,\sigma_1^{G_2}(v_1)$$
$$r_2\,\sigma_1^{G_1}(u_1) + r_1k_1 = r_2\,\sigma_1^{G_1}(v_1) + r_1k_1$$
$$r_2\,\sigma_1^{G_1}(u_1) = r_2\,\sigma_1^{G_1}(v_1)$$
$$\sigma_1^{G_1}(u_1) = \sigma_1^{G_1}(v_1)$$

Similarly,

$$d_2^{G_1\times_m G_2}(u_1, u_2) = d_2^{G_1\times_m G_2}(v_1, v_2)$$
$$d^{G_2^*}(u_2)\,\sigma_2^{G_1}(u_1) + d^{G_1^*}(u_1)\,\sigma_2^{G_2}(u_1)$$
$$= d^{G_2^*}(v_2)\,\sigma_2^{G_1}(v_1) + d^{G_1^*}(v_1)\,\sigma_2^{G_2}(v_1)$$
$$r_2\sigma_2^{G_1}(u_1) + r_1k_2 = r_2\sigma_2^{G_1}(v_1) + r_1k_2$$
$$\sigma_2^{G_1}(u_1) = \sigma_2^{G_1}(v_1)$$

This is true for all vertices in V_1. Hence $\sigma_1^{G_1}$ and $\sigma_2^{G_2}$ are constant functions.

V. CONCLUSION

Intuitionistic fuzzy graphs play an important role in uncertainty quantification in networking, route mapping, shortest path problem, etc... Intuitionistic fuzzy model are more realistic compared to other fuzzy and interval-valued fuzzy models. In this paper, the degree of a vertex in max-product of two given intuitionistic fuzzy graph is studied. The necessary and sufficient condition for the max-product of two given intuitionistic fuzzy graph to be regular are stated and proved. In future, we will extend these results in some new operations on intuitionistic fuzzy graph and interval-valued intuitionistic fuzzy graph.

ACKNOWLEDGMENT

The authors extend their sincere thanks to the anonymous reviewers and Editor-in-Chief for their valuable comments and suggestion to improve the quality of the research paper.

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