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INTERVAL VALUED REGULAR NEUTROSOPHIC GRAPH

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Abstract

In this paper, we present the definitions of regular interval valued neutrosophic graphs and we present the concept of regular interval valued neutrosophic graphs and examine the properties of this new concept and example.

Keywords: Neutrosophic graph; complete neutrosophic graph; bipartite neutrosophic graph; complement neutrosophic graph; and integral valued regular neutrosophic graph.

1. Introduction

Smarandache[12] introduced the idea of the neutrosophic set, by modifying the concept of the fuzzy set. The neutrosophic set can work with uncertain, inderminate vague and inconsistent information of any uncertain real-life problem. It is basically a modified version of the crisp set, Type 1 fuzzy set and IFS. It is described by the truth, indeterminate and always lie within $]^{-}0, 1^{+}[$, i.e., a nonstandard unit interval. The neutrosophic graph Smarandache [11] can efficiently model the inconsistent information about any real-life problem.

The vertex degree is a significant way to represent the total number of relations of a vertex in a graph and the vertex degree can be used to analyze the graph. Gani and Latha et al,[9] proposed the concept of irregularity, total irrationality and total degree in a fuzzy graph. Maheswari and Sekar[10] proposed the notation of the d_2-vertex in a fuzzy graph and also described several properties on the d_2-vertex of a fuzzy graph. Darabian et al,[7] presented the idea of the d_m-regular vague graph td_m-regular vague graph. They described some real-life applications (e.g., fullerence molecules, wireless network and road network) of regular vague graphs. Neutrosophic graphs are more effective, flexible and compatible when modeling uncertain real-life problems copared to fuzzy graphs are vague graphs. Thus, the use of the netutrosophic graph is inevitable for modeling optimaization problems in real-life scenarios and it is essential to present some new properties and theories for neutrosophic graphs. This idea motivates us to introduce different types of neutrosophic graphs (regular, bipatite, isomorphic and μ complement neutrosophic graphs) and their related theorems.

The concept of the regularity and degree of nodes has a significant role in both theories and application(e.g., social network analysis,road transportation network, wireless multihop network and the assignment problem) in neutrosophic graph theroy. The main contributions of this manuscript are as follows.

(i) As far as we know, there exists no research work on the regularity of the neutrosophic graph until now. Therefore, in this manuscript, we present the definition of the interval valued regular neutrosophic graph.

(ii) We introduce the two type of degree, d_m-and total d_m-degrees, of a node in a neutrosophic graph. The definition of busy and free nodes in a regular neutrosophic graph are presented here.

2. Preliminaries

We denote $G^* = (V, E)$ a crisp graph and $G = (A, B)$ an interval valued neutrosophic graphs.

Definition 2.1. *Let X be a space of points (objects) with generic elements in X denoted by x; then the neutrosophic set A (NS) is an object having the form* $A = \{< x : T_A(X), I_A(X), F_A(X) >, x \in X\}$, *where the function* $T, I, F : X \to]-0, 1+[$ *define respectively the a truth-membership function, an indeterminacy-membership function and falsity-membership function of the element* $x \in X$ *to the set A with the condition:*

$$^{-}0 \leq T_A(X) + I_A(X) + F_A(X) \leq 3^{+}$$

The functions $T_A(X)$,$I_A(X)$ *and* $F_A(X)$ *are real standard or nonstandard subsets of* $]^{-}0, 1^{+}[$.

Definition 2.2. *Let X be a space of points (objects) with generic elements in X denoted by x. A single valued neutrosophic set A (SVNS) is characterized by truth-membership function* $T_A(X)$, *an indeterminacy-membership function* $I_A(X)$ *and a falsity-membership function* $F_A(X)$. *For each point x in X* $T_A(X), I_(X), F_A(X) \in [0, 1]$. *A SVNS A can be written as*

$$A = \{< x : T_A(X), I_A(X), F_A(X) >, x \in X\}$$

Definition 2.3. *By an interval valued neutrosophic graph of a graph $G^* = (V, E)$ we mean a pair $G = (A, B)$, where $A =< [T_{AL}, T_{AU}], [I_{AL}, I_{AU}], [F_{AL}, F_{AU}] >$ is an IVN set on V and $B =< [T_{BL}, T_{BU}], [I_{BL}, I_{BU}], [F_{BL}, F_{BU}] >$ is an interval valued neutrosophic relation on E satisfies the following condition:*

1. *$V = \{v_1, v_2, \cdots, v_n\}$ such that $T_{AL} : [0, 1]$, $T_{AU} : [0, 1]$, $I_{AL} : [0, 1]$, $I_{AU} : [0, 1]$ and $F_{AL} : [0, 1]$, $F_{AU} : [0, 1]$ denote the degree of truth-membership, the degree of indeterminacy membership and falsify-membership of the element $y \in V$, respectively and*
$$0 \leq T_A(v_i) + I_A(v_i) + F_A(v_i) \leq 3$$
for all $V_i \in V(i = 1, 2, \cdots, n)$.

2. *The functions $T_{BL} : V \times V \to [0, 1]$,$T_{BU} : V \times V \to [0, 1]$,$I_{BL} : V \times V \to [0, 1]$,$I_{BU} : V \times V \to [0, 1]$and $F_{BL} : V \times V \to [0, 1]$,$F_{BU} : V \times V \to [0, 1]$ are such that*
$$\begin{array}{ll} T_{BL}(\{v_i, v_j\}) \leq \min [T_{AL}(v_i), T_{AL}(v_j)], & T_{BU}(\{v_i, v_j\}) \leq \min [T_{AU}(v_i), T_{AU}(v_j)] \\ I_{BL}(\{v_i, v_j\}) \geq \max [I_{AL}(v_i), I_{AL}(v_j)], & I_{BU}(\{v_i, v_j\}) \geq \max [I_{AU}(v_i), I_{AU}(v_j)] \\ F_{BL}(\{v_i, v_j\}) \geq \max [F_{AL}(v_i), F_{AL}(v_j)], & F_{BU}(\{v_i, v_j\}) \geq \max [F_{AU}(v_i), F_{AU}(v_j)] \end{array}$$
Denote the degree of truth-membership, indeterminacy-membership and falsify-membership of the edge $(v_i, v_j) \in E$ respectively, where
$$0 \leq T_B(\{v_i, v_j\}) + I_A(\{v_i, v_j\}) + F_A(\{v_i, v_j\}) \leq 3$$
for all $V_i \in E(i = 1, 2, \cdots, n)$.

We call A the interval valued neutrosophic vertex set of V, B the interval valued neutrosophic edge set of E, respectively, Note that B is a symmetric interval valued neutrosophic relation on A. We use the notation (v_i, v_j) for an element of E. Thus, $G = (A, B)$ is an interval valued neutrosophic graph of $G^* = (V, E)$ if

$$\begin{array}{ll} T_{BL}(\{v_i, v_j\}) \leq \min [T_{AL}(v_i), T_{AL}(v_i)], & T_{BU}(\{v_i, v_j\}) \leq \min [T_{AU}(v_i), T_{AU}(v_i)] \\ I_{BL}(\{v_i, v_j\}) \geq \max [I_{AL}(v_i), I_{AL}(v_i)], & I_{BU}(\{v_i, v_j\}) \geq \max [I_{AU}(v_i), I_{AU}(v_i)]\text{and} \\ F_{BL}(\{v_i, v_j\}) \geq \max [F_{AL}(v_i), F_{AL}(v_i)], & F_{BU}(\{v_i, v_j\}) \geq \max [F_{AU}(v_i), F_{AU}(v_i)] \end{array}$$

for all $(v_i, v_j) \in E$.

Definition 2.4. *Let $G = (A, B)$ be an IVNG. If G has a path P of path length k from node a to nod b in G such as $P = \{a = a_1, (a_1, a_2), a_2, \cdots, a_{k-1}, (a_{k-1}, a_k), a_k = b\}$,* *then* $(T^k_{BL}(a,b), T^k_{BU}(a,b))$,$(I^k_{BL}(a,b), I^k_{BU}(a,b))$ *and* $(F^k_{BL}(a,b), F^k_{BU}(a,b))$ *are described as follows.*

$$\begin{aligned}
T^k_{BL}(a,b) &= \sup(T_{BL}(a,a_1) \wedge T_{BL}(a_1,a_2) \wedge \cdots \wedge T_{BL}(a_{k-1},a_k))\\
T^k_{BU}(a,b) &= \sup(T_{BU}(a,a_1) \wedge T_{BU}(a_1,a_2) \wedge \cdots \wedge T_{BU}(a_{k-1},a_k))\\
I^k_{BL}(a,b) &= \inf(I_{BL}(a,a_1) \vee I_{BL}(a_1,a_2) \vee \cdots \vee I_{BL}(a_{k-1},a_k))\\
I^k_{BU}(a,b) &= \inf(I_{BU}(a,a_1) \vee I_{BU}(a_1,a_2) \vee \cdots \vee I_{BU}(a_{k-1},a_k))\\
F^k_{BL}(a,b) &= \inf(F_{BL}(a,a_1) \vee F_{BL}(a_1,a_2) \vee \cdots \vee F_{BL}(a_{k-1},a_k))\\
F^k_{BU}(a,b) &= \inf(F_{BU}(a,a_1) \vee F_{BU}(a_1,a_2) \vee \cdots \vee F_{BU}(a_{k-1},a_k))
\end{aligned}$$

Definition 2.5. *Let* $G = (A,B)$ *be an IVNG. The strength of connection of a path* P *between two nodes* a *and* b *is defined by* $(T^\infty_{BL}(a,b), T^\infty_{BU}(a,b))$,$(I^\infty_{BL}(a,b), I^\infty_{BU}(a,b))$ *and* $(F^\infty_{BL}(a,b), F^\infty_{BU}(a,b))$, *where*

$$\begin{aligned}
T^\infty_{BL}(a,b) &= \sup\{T^k_{BL}(a,b)|,\ \ k = 1,2,\cdots,\}\\
T^\infty_{BU}(a,b) &= \sup\{T^k_{BU}(a,b)|,\ \ k = 1,2,\cdots,\}\\
I^\infty_{BL}(a,b) &= \inf\{I^k_{BL}(a,b)|,\ \ k = 1,2,\cdots,\}\\
I^\infty_{BU}(a,b) &= \inf\{I^k_{BU}(a,b)|,\ \ k = 1,2,\cdots,\}\\
F^\infty_{BL}(a,b) &= \inf\{F^k_{BL}(a,b)|,\ \ k = 1,2,\cdots,\}\\
F^\infty_{BU}(a,b) &= \inf\{F^k_{BU}(a,b)|,\ \ k = 1,2,\cdots,\}
\end{aligned}$$

3. Interval Valued Regular, d_m-Regular and td_m-Regular Neutrosophic Graphs

In this section, first we define the interval valued regular neutrosophic graph, interval valued regular strong neutrosophic graph, d_m-degree and td_m-degree of nodes in a neutrosophic graph. Then, we propose the notions of d_m and td_m-interval valued regular neutrosophic graphs and prove the necessary and sufficient conditions, for which under these conditions, d_m-interval valued regular with td_m-regular neutrosophic graphs are equivalent.

Definition 3.1. *Let $G = (A, B)$ be an IVNG. Gis a interval valued regular neutrosophic graph if it satisfies the following conditions.*

$$\sum_{a \neq b} T_{BL}(a,b) = constant, \qquad \sum_{a \neq b} T_{BU}(a,b) = constant,$$
$$\sum_{a \neq b} I_{BL}(a,b) = constant, \qquad \sum_{a \neq b} I_{BU}(a,b) = constant,$$
$$\sum_{a \neq b} F_{BL}(a,b) = constant, \qquad \sum_{a \neq b} F_{BU}(a,b) = constant,$$

Definition 3.2. *Let $G = (A, B)$ be an IVNG. G is a interval valued regular strong neutrosophic graph if it satisfies the following conditions.*

$$T_{BL}(a,b) = \min((T_{AL}(a), T_{AL}(b))) \ \ and \ \sum_{a \neq b} T_{BL}(a,b) = constant$$
$$T_{BU}(a,b) = \min((T_{AU}(a), T_{AU}(b))) \ \ and \ \sum_{a \neq b} T_{BU}(a,b) = constant$$
$$I_{BL}(a,b) = \max((I_{AL}(a), I_{AL}(b))) \ \ and \ \sum_{a \neq b} I_{BL}(a,b) = constant$$
$$I_{BU}(a,b) = \max((I_{AU}(a), I_{AU}(b))) \ \ and \ \sum_{a \neq b} I_{BU}(a,b) = constant$$
$$F_{BL}(a,b) = \max((F_{AL}(a), F_{AL}(b))) \ \ and \ \sum_{a \neq b} F_{BL}(a,b) = constant$$
$$F_{BU}(a,b) = \max((F_{AU}(a), F_{AU}(b))) \ \ and \ \sum_{a \neq b} F_{BU}(a,b) = constant$$

Definition 3.3. *Let $G = (A, B)$ be an IVNG and the d_m-degree of any node a in G be denote as $d_m(a)$ where:*

$$d_m(a) = \Big(\sum_{a \neq b \in V} (T^m_{BL}(a,b), T^m_{BU}(a,b)) \sum_{a \neq b \in V} (I^m_{BL}(a,b), I^m_{BU}(a,b)), \sum_{a \neq b \in V} (F^m_{BL}(a,b), F^m_{BU}(a,b)) \Big)$$

Here, the path $a, a_1, a_2, \cdots, a_{m-1}, b$ is the shortest path between the nodes u and v and the length of this path is m.

Example 3.1. *We have considered an example of an IVNG G, presented in Figure 1.*

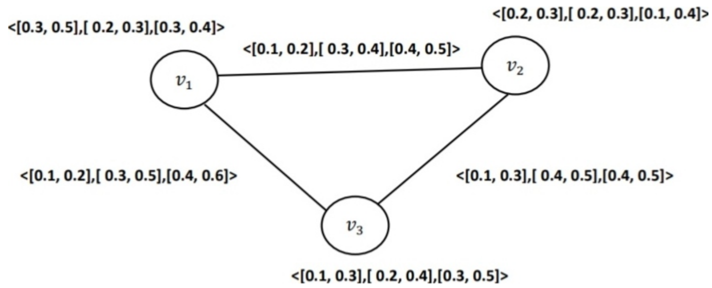

Figure 1: Interval valued neutrosophic graph

The d_2-degree of the nodes in G is computed as follows.

$$\begin{aligned}
d_2(v_1) &= ([(0.1+0.2),(0.1+0.2)],[(0.3+0.4),(0.3+0.5)],[(0.4+0.5),(0.4+0.6)]) \\
&= ([0.3,0.3],[0.7,0.8],[0.9,1.0]) \\
d_2(v_2) &= ([(0.1+0.2),(0.1+0.3)],[(0.3+0.4),(0.4+0.5)],[(0.4+0.5),(0.4+0.5)]) \\
&= ([0.3,0.4],[0.7,0.9],[0.9,0.9]) \\
d_2(v_3) &= ([(0.1+0.2),(0.1+0.3)],[(0.3+0.5),(0.4+0.5)],[(0.4+0.6),(0.5+0.5)]) \\
&= ([0.3,0.4],[0.8,0.9],[1.0,1.0])
\end{aligned}$$

Definition 3.4. *Let $G = (A, B)$ be an IVNG and $a \in V$ be a node G. The total td_m-degree (td_m-degree) of node a in G is computed as follows.*

$$\begin{aligned}
td_m(a) = \Bigg(&\Big(\sum_{a\neq b\in V}(T^m_{BL}(a,b),T^m_{BU}(a,b)) + (T_{AL}(a),T_{AU}(a))\Big),\\
&\Big(\sum_{a\neq b\in V}(I^m_{BL}(a,b),I^m_{BU}(a,b)) + (I_{AL}(a),I_{AU}(a))\Big),\\
&\Big(\sum_{a\neq b\in V}(F^m_{BL}(a,b),F^m_{BU}(a,b)) + (F_{AL}(a),F_{AU}(a))\Big)\Bigg)
\end{aligned}$$

Here, the path $a, a_1, a_2, \cdots, a_{m-1}, b$ is the shortest path between the nodes u and v and the length of this path is m.

Example 3.2. *Let us consider an example of an IVNG, shown in figure 1. Then the* td_2*-degree of the nodes in G is as follows.*

$$\begin{aligned}
td_2(v_1) =&([(0.1 + 0.2) + 0.3, (0.1 + 0.2) + 0.5], [(0.3 + 0.4) + 0.2, (0.3 + 0.5) + 0.3],\\
&[(0.4 + 0.5) + 0.3, (0.4 + 0.6) + 0.4]) = ([0.6, 0.8], [0.9, 1.1], [1.2, 1.4])\\
td_2(v_2) =&([(0.1 + 0.2) + 0.2, (0.1 + 0.3) + 0.3], [(0.3 + 0.4) + 0.2, (0.4 + 0.5) + 0.3],\\
&[(0.4 + 0.5) + 0.1, (0.4 + 0.5) + 0.4]) = ([0.5, 0.7], [0.9, 1.2], [1.0, 1.3])\\
td_2(v_3) =&([(0.1 + 0.2) + 0.1, (0.1 + 0.3) + 0.3], [(0.3 + 0.5) + 0.2, (0.4 + 0.5) + 0.4],\\
&[(0.4 + 0.6) + 0.3, (0.4 + 0.5) + 0.5]) = ([0.4, 0.7], [1.0, 1.3], [1.3, 1.4])
\end{aligned}$$

Definition 3.5. *Let* $G = (A, B)$ *be a neutrosophic graph. G is said to be a* $(m(d_1, d_2, d_3))$*-interval valued regular neurtrosophic graph or* d_m*-regular if for all nodes* $v_i \in V$ *in G,* $d_m(v_i) = (d_1, d_2, d_3)$.

Definition 3.6. *Let* $G = (A, B)$ *is a neutrosophic graph. G is an* $(m(k_1, k_2, k_3))$*- interval valued totally regular neurtrosophic graph or* td_m*- interval valued regular neutrosophic graph if for all nodes* $v_i \in V$ *G,* $td_m(v_i) = (k_1, k_2, k_3)$.

Example 3.3. *An example of an* $(m, (d_1, d_2, d_3))$*-interval valued regular neurtrosophic graph is pictured in Figure 2 is a* $(2([0.1, 0.2],\ [0.3, 0.5],\ [0.3, 0.5]))$*-interval valued regular neurtrosophic graph.*

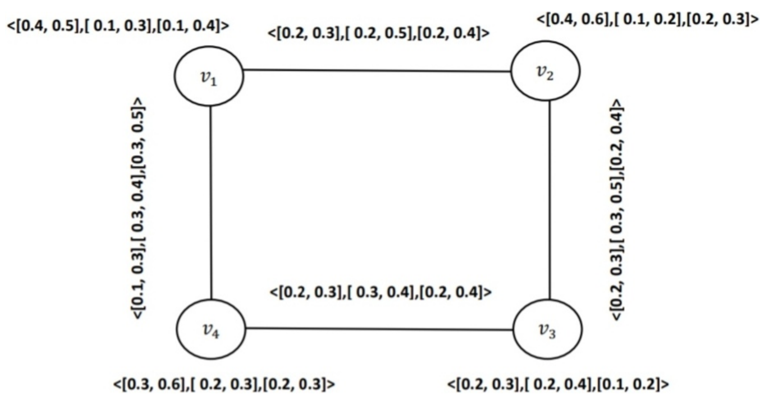

Figure 2: Interval valued neutrosophic graph G

Example 3.4. *An example of a* $(m(k_1, k_2, k_3))$*-interval valued totally regular neurtrosophic graph is shown in Figure 3. It is a* $(2, ([0.4, 0.7], [1.0, 1.3], [1.4, 1.5]))$*-interval valued regular neutrosophic graph.*

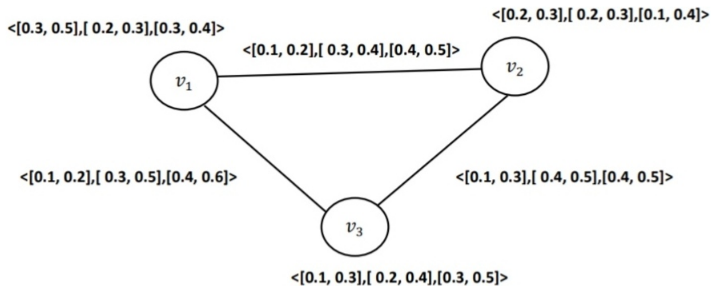

Figure 3: Interval valued neutrosophic graph G

Theorem 3.1. *Let $G = (A, B)$ be an IVNG. If (T_{BL}, T_{BU}), (I_{BL}, I_{BU}) and (F_{BL}, F_{BU}), are constant function, then G is a d_m- interval valued regular neutrosophic graph if G is a td_m-interval valued totally regular neutrosophic graph (m is a positive integer).*

Proof. Suppose that for every node v in G, $((T_{AL}(v), T_{AU}(v)), (I_{AL}(v), I_{AU}(v)),$ $(F_{AL}(v), F_{AU}(v))) = (c_1, c_2, c_3)$ and $d_m(a) = (d_1, d_2, d_3)$. Then,

$$\begin{aligned} td_m(v) &= d_m(v) + ((T_{AL}(v), T_{AU}(v)), (I_{AL}(v), I_{AU}(v)), (F_{AL}(v), F_{AU}(v))) \\ &= (d_1 + c_1, d_2 + c_2, d_3 + c_3) \end{aligned}$$

Hence, G is a td_m- interval valued regular neutrosophic graph. If G is a td_m-interval valued regular neutrosophic graph,then the proof is similar to the previous case. □

Theorem 3.2. *Let $G = (A, B)$ be an $(m(d_1, d_2, d_3))$-interval valued totally regular and an $(m(k_1, k_2, k_3)$-interval valued totally regular neurtrosophic graph with n nodes. Then, $((T_{AL}(v), T_{AU}(v)), (I_{AL}(v), I_{AU}(v))$ and $(F_{AL}(v), F_{AU}(v)))$ are constant function and $O(G) = n(k_1 - d_1, k_2 - d_2, k_3 - d_3)$.*

Proof. If G is an $(m(d_1, d_2, d_3))$-regular neurtrosophic graph and an $(m(k_1, k_2, k_3)$-totally regular neurtrosophic graph respectively, then for all $v \in V$ we get,

$$\begin{aligned} d_m(u) = (d_1, d_2, d_3) \to \Big(&\sum_{u \neq v \in V} (T^m_{BL}(uv), T^m_{BU(vu)}), \sum_{u \neq v \in V} (I^m_{BL}(uv), I^m_{BU(vu)}), \\ &\sum_{u \neq v \in V} (F^m_{BL}(uv), F^m_{BU(vu)}) = (d_1, d_2, d_3) \Big) \end{aligned}$$

and

$$td_m(u) = (k_1, k_2, k_3) \to \Big(\sum_{u \neq v \in V} \big((T^m_{BL}(uv), T^m_{BU}(vu)) + (T_{AL}(v), T_{AU}(v)) \big), \sum_{u \neq v \in V} \big((I^m_{BL}(uv), I^m_{BU(vu)}) + (I_{AL}(v), I_{AU}(v)) \big), \sum_{u \neq v \in V} \big((F^m_{BL}(uv), F^m_{BU(vu)}) + (F_{AL}(v), F_{AU}(v)) \big) \Big) = (k_1, k_2, k_3)$$

$(d_1, d_2, d_3) = (k_1 - (T_{AL}(v), T_{AU}(v)), k_2 - (I_{AL}(v), I_{AU}(v)), k_3 - (F_{AL}(v), F_{AU}(v)))$
and so
$((T_{AL}(v), T_{AU}(v)), (I_{AL}(v), I_{AU}(v)), (F_{AL}(v), F_{AU}(v))) = (k_1 - d_1, k_2 - d_2, k_3 - d_3)$.
Then (T_{AL}, T_{AU}), (I_{AL}, I_{AU}) and (F_{AL}, F_{AU}) are constant function and since G has n nodes, we get:

$$O(G) = \Big(\sum_{u \in V} \big(T_{AL}(v), T_{AU}(v) \big), \sum_{u \in V} \big(I_{AL}(v), I_{AU}(v) \big), \sum_{u \in V} \big(F_{AL}(v), F_{AU}(v) \big) \Big)$$
$$= n(k_1 - d_1, k_2 - d_2, k_3 - d_3)$$

□

4. Conclusion

Interval valued neutrosophic graph have been introduced and investigated in this paper. The natural extension of this research work is the application of interval valued neutrosophic graph in the area of soft computing including neural network, expert systems, database theory, and geographical information system.

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