INTERVAL VALUED NEUTROSOFPIC GRAPHS

Said BROUMI 1,(broumisaid78@gmail.com), Mohamed TALEA2 (taleamohamed@yahoo.fr), Assia BAKALI3 (assibakali@yahoo.fr), Florentin SMARANDACHE4 (fsmarandache@gmail.com)

1,2 Laboratory of Information processing, Faculty of Science Ben M’Sik, University Hassan II, B.P 7955, Sidi Othman, Casablanca, Morocco.
3Ecole Royale Navale-Boulevard Sour Jdid, B.P 16303 Casablanca, Morocco,
4Department of Mathematics, University of New Mexico,705 Gurley Avenue, Gallup, NM 87301, USA

The notion of interval valued neutrosophic sets is a generalization of fuzzy sets, intuitionistic fuzzy sets, interval valued fuzzy sets, interval valued intuitionistic fuzzy sets and single valued neutrosophic sets. We apply for the first time the concept of interval valued neutrosophic sets, an instance of neutrosophic sets, to graph theory. We introduce certain types of interval valued neutrosophic graphs (IVNG) and investigate some of their properties with proofs and examples.

Keywords: Interval valued neutrosophic set, interval valued neutrosophic graph, strong interval valued neutrosophic graph, constant interval valued neutrosophic graph, complete interval valued neutrosophic graph, degree of interval valued neutrosophic graph.

1. PRELIMINARIES

Neutrosophic sets (NSs) proposed by Smarandache [13, 14] is a powerful mathematical tool for dealing with incomplete, indeterminate and inconsistent information in real world. They are a generalization of the theory of fuzzy sets [31], intuitionistic fuzzy sets [28, 30], interval valued fuzzy set [23] and interval-valued intuitionistic fuzzy sets [29]. The neutrosophic sets are characterized by a truth-membership function (t), an indeterminacy-membership function (I) and a falsity-membership function (f) independently, which are within the real standard or nonstandard unit interval ]0, 1[. In order to practice NS in real life applications conveniently, Wang et al. [17] introduced the concept of a single-valued neutrosophic sets (SVNS), a subclass of the neutrosophic sets. The same authors [16, 18] introduced the concept of interval valued neutrosophic sets (IVNS), which is more precise and flexible than single valued neutrosophic sets. The IVNS is a generalization of single valued neutrosophic sets, in which three membership functions are independent and their value belong to the unit interval ]0, 1[. Some more work on single valued neutrosophic sets, interval valued neutrosophic sets and their applications may be found on [3-6, 19-27, 39, 41-48, 52, 56].

Graph theory has now become a major branch of applied mathematics and it is generally regarded as a branch of combinatorics. Graph is a widely used tool for solving a combinatorial problems in different areas such as geometry, algebra, number theory, topology, optimization and computer science [49-51]. Most important thing which is to be noted is that, when we have uncertainty regarding either the set of vertices or edges or both, the model becomes a fuzzy graph. The extension of fuzzy graph [7, 9, 38] theory have been developed by several researchers including intuitionistic fuzzy graphs [8, 32, 40] considered the vertex sets and edge sets as intuitionistic fuzzy sets. Interval valued fuzzy graphs [33, 34] considered the vertex sets and edge sets as interval valued fuzzy sets. Interval valued intuitionistic fuzzy graphs [2, 48] considered the vertex sets and edge sets as interval valued intuitionistic fuzzy sets. Bipolar fuzzy graphs [35, 36] considered the vertex sets and edge sets as bipolar fuzzy sets. M-polar fuzzy graphs [37] considered the vertex sets and edge sets as m-polar fuzzy sets. But, when the relations between nodes(or vertices) in problems are indeterminate, the fuzzy graphs and their extensions are failed. For this purpose, Samaranadache [10, 11, 12, 54] have defined four main categories of neutrosophic graphs, two based on literal indeterminacy (I), which called them; I-edge neutrosophic graph and I-vertex neutrosophic graph, these concepts are studied deeply and has gained popularity among the researchers due to its applications via real world problems [1, 15, 53,
The two others graphs are based on (t, i, f) components and called them; The (t, i, f)-Edge neutrosophic graph and the (t, i, f)-vertex neutrosophic graph, these concepts are not developed at all. Later on, Broumi et al. [47] introduced a third neutrosophic graph model. This model allows the attachment of truth-membership (t), indeterminacy –membership (i) and falsity- membership degrees (f) both to vertices and edges, and investigated some of their properties. The third neutrosophic graph model is called single valued neutrosophic graph (SVNG for short). The single valued neutrosophic graph is the generalization of fuzzy graph and intuitionistic fuzzy graph. Also, the same authors [46] introduced neighborhood degree of a vertex and closed neighborhood degree of vertex in single valued neutrosophic graph as a generalization of neighborhood degree of a vertex and closed neighborhood degree of vertex in fuzzy graph and intuitionistic fuzzy graph. In the literature the study of interval valued neutrosophic graphs (IVN-graph) is still blank, we shall focus on the study of interval valued neutrosophic graphs in this paper.

In this paper, some certain types of interval valued neutrosophic graphs are developed and some interesting properties are explored.

2. PRELIMINARIES

In this section, we mainly recall some notions related to neutrosophic sets, single valued neutrosophic sets, interval valued neutrosophic sets, single valued neutrosophic graphs, relevant to the present work. See especially [13, 17, 18, 19] for further details and background.

**Definition 2.1** [13]. Let $X$ be a space of points (objects) with generic elements in $X$ denoted by $x$; then the neutrosophic set $A$ (NS $A$) is an object having the form $A = \{ x : T_A(x), I_A(x), F_A(x) \in [0, 1] \}$, where the functions $T, I, F : X \to [0, 1]$ define respectively the a truth membership, an indeterminacy-membership function, and a falsity-membership function of the element $x \in X$ to the set $A$ with the condition:

$$0 \leq T_A(x) + I_A(x) + F_A(x) \leq 3.$$ (1)

The functions $T_A(x), I_A(x)$ and $F_A(x)$ are real standard or nonstandard subsets of $]0,1[$.

Since it is difficult to apply NSs to practical problems, Wang et al. [16] introduced the concept of a SVNS, which is an instance of a NS and can be used in real scientific and engineering applications.

**Definition 2.2** [17]. Let $X$ be a space of points (objects) with generic elements in $X$ denoted by $x$. A single valued neutrosophic set $A$ (SVNS $A$) 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 $X$, $T_A(x), I_A(x), F_A(x) \in [0, 1]$. A SVNS $A$ can be written as

$$A = \{ x : T_A(x), I_A(x), F_A(x) \in [0, 1] \}$$ (2)

**Definition 2.3** [47]. Let $A = (T_A, I_A, F_A)$ and $B = (T_B, I_B, F_B)$ be single valued neutrosophic sets on a set $X$. If $A = (T_A, I_A, F_A)$ is a single valued neutrosophic relation on a set $X$, then $A = (T_A, I_A, F_A)$ is called a single valued neutrosophic relation on $B = (T_B, I_B, F_B)$ if

$$T_B(x, y) \leq \min(T_A(x), T_A(y)), I_B(x, y) \geq \max(I_A(x), I_A(y)) \text{ and } F_B(x, y) \leq \max(F_A(x), F_A(y)) \text{ for all } x, y \in X.$$ A single valued neutrosophic relation $A$ on $X$ is called symmetric if $T_A(x, y) = T_A(y, x), I_A(x, y) = I_A(y, x), F_A(x, y) = F_A(y, x) \text{ and } T_B(x, y) = T_B(y, x), I_B(x, y) = I_B(y, x) \text{ and } F_B(x, y) = F_B(y, x), \text{ for all } x, y \in X.$

**Definition 2.4** [47]. A single valued neutrosophic graph (SVN-graph) with underlying set $V$ is defined to be a pair $G = (A, B)$ where

1. The functions $T_A: V \to [0, 1], I_A: V \to [0, 1] \text{ and } F_A: V \to [0, 1]$ denote the degree of truth-membership, degree of indeterminacy-membership and falsity-membership of the element $v_i \in V$, respectively, and

$$0 \leq T_A(v_i) + I_A(v_i) + F_A(v_i) \leq 3 \text{ for all } v_i \in V \text{ (i=1, 2, ...,n)}

2. The functions $T_B: E \subseteq V \times V \to [0, 1], I_B: E \subseteq V \times V \to [0, 1] \text{ and } F_B: E \subseteq V \times V \to [0, 1]$ are defined by

$$T_B((v_i, v_j)) \leq \min |T_A(v_i), T_A(v_j)|, \text{ } I_B((v_i, v_j)) \geq \max |I_A(v_i), I_A(v_j)| \text{ and } F_B((v_i, v_j)) \geq \max |F_A(v_i), F_A(v_j)|$$

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Denotes the degree of truth-membership, indeterminacy-membership and falsity-membership of the edge \((v_i, v_j) \in E\) respectively, where

\[0 \leq T_B([v_i, v_j]) + I_B([v_i, v_j]) + F_B([v_i, v_j]) \leq 3\]  

for all \(\{v_i, v_j\} \in E\) (i, j = 1, 2, ..., n)

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

\[T_B(v_i, v_j) \leq \min\{T_A(v_i), T_A(v_j)\}, I_B(v_i, v_j) \geq \max\{I_A(v_i), I_A(v_j)\}\]  

\[\geq \max\{F_A(v_i), F_A(v_j)\}\]  

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

![Figure 1: Single valued neutrosophic graph](image)

**Definition 2.5 [47].** Let \(G = (A, B)\) be a single valued neutrosophic graph. Then the degree of any vertex \(v\) is sum of degree of truth-membership, sum of degree of indeterminacy-membership and sum of degree of falsity-membership of all those edges which are incident on vertex \(v\) denoted by \(d(v) = (d_T(v), d_I(v), d_F(v))\) where

\[d_T(v) = \sum_{u \neq v} T_B(u, v)\]  

denotes degree of truth-membership vertex.

\[d_I(v) = \sum_{u \neq v} I_B(u, v)\]  

denotes degree of indeterminacy-membership vertex.

\[d_F(v) = \sum_{u \neq v} F_B(u, v)\]  

denotes degree of falsity-membership vertex.

**Definition 2.6 [18].** Let \(X\) be a space of points (objects) with generic elements in \(X\) denoted by \(x\). An interval valued neutrosophic set (for short IVNS-A) \(A\) in \(X\) is characterized by truth-membership function \(T_A(x)\), indeterminacy-membership function \(I_A(x)\) and falsity-membership function \(F_A(x)\). For each point \(x\) in \(X\), we have that \(T_A(x) = [T_{AL}(x), T_{AU}(x)], I_A(x) = [I_{AL}(x), I_{AU}(x)], F_A(x) = [F_{AL}(x), F_{AU}(x)] \subseteq [0, 1]\) and \(0 \leq T_A(x) + I_A(x) + F_A(x) \leq 3\).

**Definition 2.7 [18].** Let \(X\) and \(Y\) be two non-empty crisp sets. An interval valued neutrosophic relation \(R(X, Y)\) is a subset of product space \(X \times Y\), and is characterized by the truth membership function \(T_R(x, y)\), the indeterminacy membership function \(I_R(x, y)\), and the falsity membership function \(F_R(x, y)\), where \(x \in X\) and \(y \in Y\) and \(T_R(x, y), I_R(x, y), F_R(x, y) \subseteq [0, 1]\).

### 3. INTERVAL VALUED NEUTROSOPHIC GRAPHS

Through this paper, we denote \(G^* = (V, E)\) a crisp graph, and \(G = (A, B)\) an interval valued neutrosophic graph.
Definition 3.1. By an interval-valued neutrosophic graph of a graph $G^* = (V, E)$ we mean a pair $G = (A, B)$, where $A = \langle [T_{AL}, T_{AU}], [I_{AL}, I_{AU}], [F_{AL}, F_{AU}] \rangle$ is an interval-valued neutrosophic set on $V$ and $B = \langle [T_{BL}, T_{BU}], [I_{BL}, I_{BU}], [F_{BL}, F_{BU}] \rangle$ is an interval-valued neutrosophic relation on $E$ satisfies the following condition:

1. $V = \{v_1, v_2, \ldots, v_n\}$ such that $T_{AL}: V \rightarrow [0, 1], T_{AU}: V \rightarrow [0, 1], I_{AL}: V \rightarrow [0, 1], I_{AU}: V \rightarrow [0, 1]$ and $F_{AL}: V \rightarrow [0, 1], F_{AU}: V \rightarrow [0, 1]$ denote the degree of truth-membership, the degree of indeterminacy-membership and falsity-membership of the element $y \in V$, respectively, and

$$0 \leq T_A(v_i) + I_A(v_i) + F_A(v_i) \leq 3 \text{ for all } v_i \in V \text{ (i=1, 2, ..., n)}$$

2. The functions $T_{BL}: V \times V \rightarrow [0, 1], T_{BU}: V \times V \rightarrow [0, 1], I_{BL}: V \times V \rightarrow [0, 1], I_{BU}: V \times V \rightarrow [0, 1]$ and $F_{BL}: V \times V \rightarrow [0, 1], F_{BU}: V \times V \rightarrow [0, 1]$ are such that

$$T_{BL}([v_i, v_j]) \leq \min (T_{AL}(v_i), T_{AL}(v_j)), \quad T_{BU}([v_i, v_j]) \leq \min (T_{AU}(v_i), T_{AU}(v_j))$$

$$I_{BL}([v_i, v_j]) = \max (I_{BL}(v_i), I_{BL}(v_j)), \quad I_{BU}([v_i, v_j]) = \max (I_{BU}(v_i), I_{BU}(v_j))$$

And

$$F_{BL}([v_i, v_j]) = \max (F_{BL}(v_i), F_{BL}(v_j)), \quad F_{BU}([v_i, v_j]) = \max (F_{BU}(v_i), F_{BU}(v_j))$$

Denotes the degree of truth-membership, indeterminacy-membership and falsity-membership of the edge $(v_i, v_j) \in E$ respectively, where

$$0 \leq T_B([v_i, v_j]) + I_B([v_i, v_j]) + F_B([v_i, v_j]) \leq 3 \text{ for all } (v_i, v_j) \in E \text{ (i, j = 1, 2, ..., n)}$$

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

$$T_{BL}(v_i, v_j) \leq \min (T_{AL}(v_i), T_{AL}(v_j)), \quad T_{BU}(v_i, v_j) \leq \min (T_{AU}(v_i), T_{AU}(v_j))$$

$$I_{BL}(v_i, v_j) = \max (I_{BL}(v_i), I_{BL}(v_j)), \quad I_{BU}(v_i, v_j) = \max (I_{BU}(v_i), I_{BU}(v_j))$$

And

$$F_{BL}(v_i, v_j) = \max (F_{BL}(v_i), F_{BL}(v_j)), \quad F_{BU}(v_i, v_j) = \max (F_{BU}(v_i), F_{BU}(v_j))$$

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

Example 3.2. Consider a graph $G^*$ such that $V = \{v_1, v_2, v_3, v_4\}$, $E = \{v_1v_2, v_2v_3, v_3v_4, v_4v_1\}$. Let $A$ be a interval valued neutrosophic subset of $V$ and let $B$ a interval valued neutrosophic subset of $E$ denoted by

$v_2 = \langle [0.2, 0.3], [0.2, 0.3], [0.1, 0.4] \rangle$, $v_3 = \langle [0.1, 0.3], [0.2, 0.4], [0.3, 0.5] \rangle$

$v_{12} = \langle [0.1, 0.2], [0.3, 0.4], [0.4, 0.5] \rangle$, $v_{23} = \langle [0.1, 0.3], [0.4, 0.5], [0.4, 0.5] \rangle$

$v_{13} = \langle [0.1, 0.2], [0.3, 0.5], [0.4, 0.6] \rangle$

$v_{14} = \langle [0.3, 0.5], [0.2, 0.3], [0.3, 0.4] \rangle$, $v_{24} = \langle [0.2, 0.3], [0.2, 0.3], [0.1, 0.4] \rangle$

$v_{34} = \langle [0.1, 0.3], [0.4, 0.5], [0.4, 0.5] \rangle$

$v_{1}v_{2}$

$v_{2}v_{3}$

$v_{3}v_{4}$

$v_{4}v_{1}$

Figure 2:G: Interval valued neutrosophic graph
The interval valued neutrosophic graph G depicted in figure 3 is represented by the following adjacency matrix $M_G$

$$M_G =
\begin{bmatrix}
[0.3, 0.5], [0.2, 0.3], [0.3, 0.4] & < [0.1, 0.2], [0.3, 0.4], [0.4, 0.5] > & < [0.1, 0.2], [0.3, 0.5], [0.4, 0.6] > \\
< [0.1, 0.2], [0.3, 0.4], [0.4, 0.5] > & < [0.2, 0.3], [0.2, 0.3], [0.1, 0.4] > & < [0.1, 0.3], [0.4, 0.5], [0.4, 0.5] > \\
< [0.1, 0.2], [0.3, 0.5], [0.4, 0.6] > & < [0.1, 0.3], [0.4, 0.5], [0.4, 0.5] > & < [0.1, 0.3], [0.2, 0.4], [0.3, 0.5] >
\end{bmatrix}$$

**Definition 3.3.** Let $G=(A, B)$ be an interval valued neutrosophic graph. Then the degree of any vertex $v$ is sum of degree of truth-membership, sum of degree of indeterminacy-membership and sum of degree of falsity-membership of all those edges which are incident on vertex $v$ denoted by $\text{d}(v) = ([d_{TL}(v), d_{TU}(v)], [d_{IL}(v), d_{IU}(v)], [d_{FL}(v), d_{FU}(v)])$ where

- $d_{TL}(v) = \sum_{u \neq v} T_{BL}(u, v)$ denotes degree of lower truth-membership vertex.
- $d_{TU}(v) = \sum_{u \neq v} T_{BU}(u, v)$ denotes degree of upper truth-membership vertex.
- $d_{IL}(v) = \sum_{u \neq v} I_{BL}(u, v)$ denotes degree of lower indeterminacy-membership vertex.
- $d_{IU}(v) = \sum_{u \neq v} I_{BU}(u, v)$ denotes degree of upper indeterminacy-membership vertex.
- $d_{FL}(v) = \sum_{u \neq v} F_{BL}(u, v)$ denotes degree of lower falsity-membership vertex.
- $d_{FU}(v) = \sum_{u \neq v} F_{BU}(u, v)$ denotes degree of upper falsity-membership vertex.

**Example 3.4.** Let us consider an interval valued neutrosophic graph $G=(A, B)$ of $G^*=(V, E)$ where $V = \{v_1, v_2, v_3, v_4\}$ and $E = \{v_1v_2, v_2v_3, v_3v_4, v_4v_1\}$. 

![Figure 4: Degree of vertex of interval valued neutrosophic graph.](image)

We have, the degree of each vertex as follows:

- $d(v_1) = ([0.3, 0.6], [0.5, 0.9], [0.5, 0.9])$
- $d(v_2) = ([0.4, 0.6], [0.5, 1.0], [0.4, 0.8])$
- $d(v_3) = ([0.4, 0.6], [0.6, 0.8], [0.5, 0.9])$
- $d(v_4) = ([0.3, 0.6], [0.6, 0.8], [0.5, 0.9])$

**Definition 3.5.** An interval valued neutrosophic graph $G=(A, B)$ is called constant if degree of each vertex is $k = ([k_{1L}, k_{1U}], [k_{2L}, k_{2U}], [k_{3L}, k_{3U}])$. That is, $d(v) = ([k_{1L}, k_{1U}], [k_{2L}, k_{2U}], [k_{3L}, k_{3U}])$ for all $v \in V$.

**Definition 3.6.** An interval valued neutrosophic graph $G=(A, B)$ of $G^*=(V, E)$ is called strong interval valued neutrosophic graph if $T_{BL}(v_i, v_j) = \min [T_{AL}(v_i), T_{AU}(v_j)]$, $T_{BU}(v_i, v_j) = \min [T_{AL}(v_i), T_{AU}(v_j)]$.
\[ l_{BL}(v_i, v_j) = \max \{ l_{AL}(v_i), l_{BL}(v_j) \}, \quad l_{BU}(v_i, v_j) = \max \{ l_{AU}(v_i), l_{AU}(v_j) \} \]

\[ F_{BL}(v_i, v_j) = \max \{ F_{AL}(v_i), F_{AL}(v_j) \}, \quad F_{BU}(v_i, v_j) = \max \{ F_{AU}(v_i), F_{AU}(v_j) \}, \text{ for all } (v_i, v_j) \in E. \]

**Example 3.7.** Consider a graph \( G^* \) such that \( V = \{ v_1, v_2, v_3, v_4 \} \), \( E = \{ v_1 v_2, v_2 v_3, v_3 v_4, v_4 v_1 \} \). Let \( A \) be an interval valued neutrosophic subset of \( V \) and let \( B \) an interval valued neutrosophic subset of \( E \) denoted by

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\[ \langle [0.1, 0.3], [0.2, 0.4], [0.3, 0.5] \rangle \]

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\[ \langle [0.1, 0.3], [0.2, 0.4], [0.3, 0.4] \rangle \]

By routing computations, it is easy to see that \( G \) is a strong interval valued neutrosophic of \( G^* \).

**Definition 3.8.** The complement of an interval valued neutrosophic graph \( G \) \((A, B)\) on \( G^* \) is an interval valued neutrosophic graph \( \bar{G} \) on \( G^* \) where:
1. \( \bar{A} = A \)
2. \( \bar{T}_{AL}(v_i) = T_{AL}(v_i), \bar{T}_{AU}(v_i) = T_{AU}(v_i), \bar{I}_{AL}(v_i) = I_{AL}(v_i), \bar{I}_{AU}(v_i) = I_{AU}(v_i), \bar{F}_{AL}(v_i) = F_{AL}(v_i), \bar{F}_{AU}(v_i) = F_{AU}(v_i) \), for all \( v_i \in V \).
3. \( \bar{T}_{BL}(v_i, v_j) = \min \{ T_{BL}(v_i, v_j) \} \), \( \bar{T}_{BU}(v_i, v_j) = \min \{ T_{BU}(v_i, v_j) \} \), \( \bar{I}_{BL}(v_i, v_j) = \max \{ I_{BL}(v_i, v_j) \} \), \( \bar{I}_{BU}(v_i, v_j) = \max \{ I_{BU}(v_i, v_j) \} \), and \( \bar{F}_{BL}(v_i, v_j) = \max \{ F_{BL}(v_i, v_j) \} \), \( \bar{F}_{BU}(v_i, v_j) = \max \{ F_{BU}(v_i, v_j) \} \), for all \( v_i, v_j \in E \).

**Proposition 3.9.** \( G = \bar{G} \) if and only if \( G \) is a strong interval valued neutrosophic graph.

**Proof.** It is obvious.

**Definition 3.10.** A strong interval valued neutrosophic graph \( G \) is called self complementary if \( G \equiv \bar{G} \).

Where \( \bar{G} \) is the complement of interval valued neutrosophic graph \( G \).

**Definition 3.11.** An interval valued neutrosophic graph \( G \) \((A, B)\) is called complete if
\[ T_{BL}(v_i, v_j) = \min (T_{AL}(v_i), T_{AL}(v_j)), T_{BU}(v_i, v_j) = \min (T_{AU}(v_i), T_{AU}(v_j)), \]
\[ I_{BL}(v_i, v_j) = \max (I_{AL}(v_i), I_{AL}(v_j)), I_{BU}(v_i, v_j) = \max (I_{AU}(v_i), I_{AU}(v_j)), \]
\[ F_{BL}(v_i, v_j) = \max (F_{AL}(v_i), F_{AL}(v_j)), F_{BU}(v_i, v_j) = \max (F_{AU}(v_i), F_{AU}(v_j)) \], and
\[ F_{BU}(v_i, v_j) = \max(F_A(v_i), F_A(v_j)), \quad F_{BU}(v_i, v_j) = \max(F_{AU}(v_i), F_{AU}(v_j)), \] for all \( v_i, v_j \in V \).

4. CONCLUSION

In this paper, we have defined, for the first time, certain types of interval valued neutrosophic graphs, such as strong interval valued neutrosophic graph, constant interval valued neutrosophic graph and complete interval valued neutrosophic graphs. In future study, we plan to extend our research to regular interval valued neutrosophic graphs and irregular interval valued neutrosophic.

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