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Novel Domination Parameter in Fuzzy Graph Theory Based on K-Integrity Measures

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Abstract
This paper proposes a novel domination parameter in fuzzy graph theory, termed the k-integrity fuzzy domination number, denoted by $\gamma_k^f(G)$. The parameter is defined as the minimum cardinality of a vertex subset $D \subseteq V$ such that the aggregated minimum fuzzy adjacency from each member of D to all vertices in the graph satisfies the threshold condition: $\sum_{u \in D} \min_{v \in V} \sigma(u,v) \geq k$. This approach combines structural control with fuzzy membership power, improving the traditional domination model by considering how it can be made stronger in uncertain situations.

INTRODUCTION

In the increasing scenario of graph theory, the perception of domination plays a fundamental role in the analysis of the network where the effect, coverage, or control is of interest. Traditionally, in a crisp graph $G = (V, E)$, a dominating set $D \subseteq V$ is defined in such a way that D does not have each vertex. At least one member of D. is adjacent to one member. Domination number $\gamma(G)$, which is the minimum cardinality of such sets, has become a fundamental metric in combinatorial optimization and network analysis (Haynes, Hedetniemi, & Slater, 1998). However, as real-world systems become more complex, the binary representation of relationships in classical models becomes insufficient, whether in social and biological networks or uncertain computational frameworks. This phenomenon has inspired the development of fuzzy graph theory, where the edges (and potentially corners) are associated with the degree of membership, capturing the uncertainty and ambiguity contained in real systems (Rosenfeld, 1975).

In a fuzzy graph $G^f = (V, \sigma)$, the fuzzy adjacency function $\sigma: V \times V \to [0,1]$ determines the power of the association between vertis. This structure allows modeling of more naturally or potential relationships more naturally than classical grains. In this context, the perception of domination also develops in fuzzy domination, where a fuzzy dominating set $D \subseteq V$ ensures that each vertex is "influenced" by some member of D to a degree determined by fuzzy membership values. The fuzzy domination number $\gamma^f(G)$ has been massively studied and defined on the basis of festive richness or effects that have been affected by the dominated vertices (Somasundaram & Murugesan, 2004).

Despite its expressive power, a model with traditional fuzzy domination often leads to a clear criterion for structural flexibility or strength. In many practical scenarios, it is insufficient to achieve only fuzzy coverage—it is also required to determine how "strong" or "safe" the effect of a dominant set is, especially under the uncertainty or partial decline of the network. This limit takes us to integrate integrity obstacles with fuzzy domination. The concept of integrity in the graph, as is introduced by Barefoot, entrance and Swart (1987), refers to the minimum number of vertices that must be removed to disconnect the graph or reduce its size significantly. When translated into fuzzy graph settings, the integrity of domination (Ramalingam et al., 2020) provides a measure of the structural effectiveness of a dominant set in an uncertain atmosphere. However, integrity is generally considered in terms of structural breakdown rather than a soft matrix such as fuzzy membership or influence capacity.

To bridge this gap, here propose a novel hybrid parameter in fuzzy graph theory-the k-integrity fuzzy domination number, denoted as $\gamma_k^f(G)$. This new parameter embeds robustness directly into the domination model by introducing a threshold k that the aggregated fuzzy adjacency of the dominating set must exceed. The definition is as follows:

$$\gamma_k^f(G) = \min\left\{|D| : D \subseteq V, \sum_{u \in D} \min_{v \in V} \sigma(u,v) \geq k\right\}$$

Here, the aggregation term $\sum_{u\in D}\min_{v\in V}\sigma(u,v)$ ensures that the selected dominating set D not only provides coverage but also possesses collective fuzzy influence strength surpassing a resilience threshold k. This approach builds on traditional fuzzy domination and adds a measure of resilience, making it useful for situations with uncertainty, partial failures, or challenging conditions.

This approach creates and expands ideas from many research domains. Sivasankar and Karunambigai (2017) discovered safe domination in fuzzy and intuition fuzzy graphs and proposed that domination should be not only functional but also under certain conditions. Ganesan, Raman, and Pal (2022) came up with the idea of strong domination integrity in fuzzy graphs, which tries to combine integrity with dominant features, but it doesn't directly involve fuzzy aggregation as we define it with our threshold.

Recent studies by Rao et al. (2024) on fuzzy coalition graphs highlight how important it is for groups to work together and influence each other in uncertain networks. These works hint at the increasing importance of models that incorporate both uncertainty and quantifiable strength in influence propagation. The model is also based on the concept of resilient fuzzy domination (Rasool et al., 2025), which means that domination should remain effective even when there are changes or some inconsistencies in edge weights.

Preliminaries

Let $G=(V,\sigma)$ be a fuzzy graph, where V is a finite non-empty set of vertices and $\sigma: V\times V\rightarrow[0,1]$ is a fuzzy adjacency function representing the degree of connection between each pair of vertices. In an undirected fuzzy graph, the function is symmetric, i.e., $\sigma(u,v)=\sigma(v,u)$, and it is typically assumed that $\sigma(u,u)=0$ for all $u\in V$. For any vertex $u\in V$, the minimum fuzzy adjacency is defined as $\min_{v\in V}\sigma(u,v)$, indicating the weakest link from u to the graph. A subset $D\subseteq V$ is called a k-integrity fuzzy dominating set if it satisfies the inequality $\sum_{u\in D}\min_{v\in V}\sigma(u,v)\geq k$, where $k\in\mathbb{R}^{+}$is a fixed threshold. k-Integrity fuzzy Domination Number, denoted $\gamma_k^f(G)$, is the minimum cardinality of such sets. This parameter normalizes classical domination by incorporating fuzzy adjacent and applying structural flexibility under uncertainty.

Definition

Let $G=(V,\sigma)$ be a fuzzy graph, where $\sigma: V\times V\rightarrow[0,1]$ denotes the fuzzy adjacency function. For each vertex $u\in V$, define the minimum fuzzy adjacency of u as

$$\mu(u)=\min_{v\in V}\sigma(u,v)$$

A non-empty subset $D\subseteq V$ is called a k-integrity fuzzy dominating set of G if it satisfies the condition

$$\sum_{u\in D}\mu(u)\geq k$$

where $k\in\mathbb{R}^{+}$is a given threshold. The k-integrity fuzzy domination number of G, denoted by $\gamma_k^f(G)$, is defined as

$$\gamma_k^f(G)=\min\left\{|D|: D\subseteq V,\sum_{u\in D}\min_{v\in V}\sigma(u,v)\geq k\right\}$$

This parameter represents the minimum number of vertices required to ensure that the aggregated minimum fuzzy influence meets or exceeds the threshold k, providing a robust measure of domination in fuzzy graph settings.

Monotonicity of the k-integrity Fuzzy Domination Number

Theorem 1

Let $G=(V,\sigma)$ be a fuzzy graph, where V is the set of vertices and $\sigma: V\times V\rightarrow[0,1]$ is the fuzzy adjacency function. Let k_1 and k_2 be two positive real numbers such that $k_1\leq k_2$. Then the following inequality holds:

$$\gamma_{k_1}^f(G)\leq\gamma_{k_2}^f(G)$$

where $\gamma_{k_1}^f(G)$ and $\gamma_{k_2}^f(G)$ denote the k-integrity fuzzy domination numbers of the graph G corresponding to the thresholds k_1 and k_2, respectively.

Proof

Let $D_2\subseteq V$ be a k_2-integrity fuzzy dominating set of the graph G. By definition, this means that

$$\sum_{u\in D_2}\min_{v\in V}\sigma(u,v)\geq k_2$$

Since $k_1\leq k_2$, it follows that

$$\sum_{u\in D_2} \min_{v\in V} \sigma(u,v) \geq k_1$$

Thus, D_2 also satisfies the domination condition for k_1. Therefore, D_2 is a valid k_1-integrity fuzzy dominating set as well. Next, recall that $\gamma^f_{k_1}(G)$ denotes the minimal cardinality of a dominating set that satisfies the fuzzy domination condition for the threshold k_1. Since D_2 satisfies the condition for k_1, it follows that:

$$\gamma^f_{k_1}(G) \leq |D_2|$$

On the other hand, since D_2 is a k_2-integrity fuzzy dominating set, it must hold that:

$$|D_2| \geq \gamma^f_{k_2}(G)$$

because $\gamma^f_{k_2}(G)$ represents the smallest possible size of a dominating set for the threshold k_2. Therefore, combining these inequalities, obtain:

$$\gamma^f_{k_1}(G) \leq |D_2| \geq \gamma^f_{k_2}(G)$$

Thus, conclude that:

$$\gamma^f_{k_1}(G) \leq \gamma^f_{k_2}(G)$$

Example

Let $G = (V, \sigma)$ be a fuzzy graph where $V = \{v_1, v_2, v_3\}$, and the fuzzy adjacency function $\sigma: V \times V \to [0,1]$ is defined as:

$$\sigma(u,v) = \begin{bmatrix} 1 & 0.7 & 0.5 \\ 0.7 & 1 & 0.6 \\ 0.5 & 0.6 & 1 \end{bmatrix}$$

That is, $\sigma(v_1, v_2) = 0.7, \sigma(v_1, v_3) = 0.5$, and so on. Diagonal entries are 1 due to self-connection. To determine the k-integrity fuzzy domination number, $\gamma^f_k(G)$, for selected values of k, evaluate the minimum fuzzy adjacency for each vertex:

- $\min_{v\in V} \sigma(v_1, v) = \min\{1,0.7,0.5\} = 0.5$
- $\min_{v\subset V} \sigma(v_2, v) = \min\{0.7,1,0.6\} = 0.6$
- $\min_{v\subset V} \sigma(v_3, v) = \min\{0.5,0.6,1\} = 0.5$

Now consider threshold values $k_1 = 1.0$ and $k_2 = 1.5$, and determine the smallest subsets $D \subseteq V$ for which:

$$\sum_{u\in D} \min_{v\in V} \sigma(u,v) \geq k$$

For $k_1 = 1.0$:
Try $D = \{v_2\}$: sum $= 0.6$
Try $D = \{v_1, v_2\}$: sum $= 0.5 + 0.6 = 1.1$
Thus, $\gamma^f_{1.0}(G) = 2$
For $k_2 = 1.5$:
Try $D = \{v_1, v_2\}$: sum $= 1.1$
Try $D = \{v_2, v_3\}: 0.6 + 0.5 = 1.1X$
Try $D = \{v_1, v_3\}: 0.5 + 0.5 = 1.0$
Try $D = \{v_1, v_2, v_3\}: 0.5 + 0.6 + 0.5 = 1.6$
Thus, $\gamma^f_{1.5}(G) = 3$

Interpretation

Since $\gamma^f_{1.0}(G) = 2$ and $\gamma^f_{1.5}(G) = 3$, it follows that:

$$\gamma^f_{1.0}(G) < \gamma^f_{1.5}(G)$$

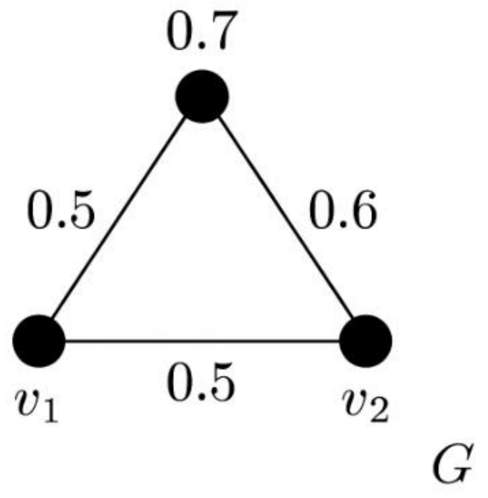

Figure 1. Fuzzy graph GGG with fuzzy adjacency values used to compute $\gamma_k^f(G)$ for varying thresholds k

Upper Bound on $\gamma_k^f(G)$ via Minimum Fuzzy Adjacency

Theorem 2

Let $G = (V, \sigma)$ be a fuzzy graph, where $\sigma: V \times V \to [0,1]$ is the fuzzy adjacency function. For any threshold $k \in (0, |V|]$, the k-integrity fuzzy domination number $\gamma_k^f(G)$ satisfies:

$$\gamma_k^f(G) \leq \left\lceil \frac{k}{\delta_{min}} \right\rceil$$

where $\delta_{min} = \min_{u \in V} \min_{v \in V} \sigma(u, v)$ is the minimum fuzzy adjacency value in the graph.

Proof

Let us denote $\delta_{min} = \min_{u \in V} \min_{v \in V} \sigma(u, v)$. By definition, for every vertex $u \in V$, the minimum value of fuzzy adjacency from u to any other vertex is at least δ_{min}. That is:

$$\forall u \in V, \min_{v \in V} \sigma(u, v) \geq \delta_{min}$$

Now, consider selecting any subset $D \subseteq V$ with $|D| = m$. Then the total aggregated minimum fuzzy adjacency over all vertices in D is:

$$\sum_{u \in D} \min_{v \in V} \sigma(u, v) \geq m \cdot \delta_{min}$$

To satisfy the condition for k-integrity fuzzy domination, we require:

$$\sum_{u \in D} \min_{v \in V} \sigma(u, v) \geq k$$

So:

$$m \cdot \delta_{min} \geq k \Rightarrow m \geq \frac{k}{\delta_{min}}$$

Therefore, the smallest integer m satisfying the inequality is:

$$m = \left\lceil \frac{k}{\delta_{min}} \right\rceil$$

This implies that there exists a dominating set $D \subseteq V$ with at most $\left\lceil \frac{k}{\delta_{min}} \right\rceil$ vertices that satisfies the k integrity fuzzy domination condition. Hence:

$$\gamma_k^f(G) \leq \left\lceil \frac{k}{\delta_{min}} \right\rceil$$

Example

Construct a nontrivial fuzzy graph to demonstrate the applicability of Theorem 2, which provides an upper bound for the k-integrity fuzzy domination number $\gamma_k^f(G)$ in terms of the minimum fuzzy adjacency value in the graph.

Let G= (V, σ) be a fuzzy graph with vertex set

V = {a, b, c, d, e, f}

and fuzzy adjacency function $\sigma: V \times V \to [0,1]$ defined as:

σ(u, v)	a	b	c	d	e	f
a	1	0.2	0.5	0.1	0.4	0.3
b	0.2	1	0.2	0.4	0.2	0.1
c	0.5	0.2	1	0.3	0.3	0.2
d	0.1	0.4	0.3	1	0.5	0.2
e	0.4	0.2	0.3	0.5	1	0.6
f	0.3	0.1	0.2	0.2	0.6	1

Minimum Fuzzy Adjacency
We compute the minimum fuzzy adjacency value for each vertex:

$$\min_{v} \sigma(a, v)$$

$$\min_{v} \sigma(b, v) = 0.1$$

$$\min_{v} \sigma(c, v) = 0.2$$

$$\min_{v} \sigma(d, v) = 0.1$$

$$\min_{v} \sigma(e, v) = 0.2$$

$$\min_{v} \sigma(f, v) = 0.1$$

Thus, the minimum fuzzy adjacency over all vertices is:

$$\delta_{\min} = \min_{u \in V} \min_{v \subset V} \sigma(u, v) = 0.1$$

Theoretical Bound via Theorem 2
Choose a threshold $k = 0.5$. According to Theorem 2:

$$\gamma_{0.5}^{f}(G) \leq \left\lceil \frac{k}{\delta_{\min}} \right\rceil = \left\lceil \frac{0.5}{0.1} \right\rceil = \lceil 5 \rceil = 5$$

This implies that any fuzzy dominating set $D \subseteq V$ satisfying the condition

$$\sum_{u \subset D} \min_{v \subset V} \sigma(u, v) \geq 0.5$$

must have at most 5 vertices.
Constructing a Fuzzy Dominating Set
We construct a candidate dominating set:

$$D = \{a, c, e\}$$

with the respective minimum adjacency values:

$$\min_{v} \sigma(a, v) = 0.1, \min_{v} \sigma(c, v) = 0.2, \min_{v} \sigma(e, v) = 0.2$$

Hence:

$$\sum_{w \in D} \min_{v} \sigma(u, v) = 0.1 + 0.2 + 0.2 = 0.5$$

Since this satisfies the domination condition with only 3 vertices, we conclude:

$$\gamma_{0.5}^{f}(G) \leq 3$$

which is consistent with the upper bound derived from Theorem 2:

$$\gamma_{0.5}^{f}(G) \leq 5$$

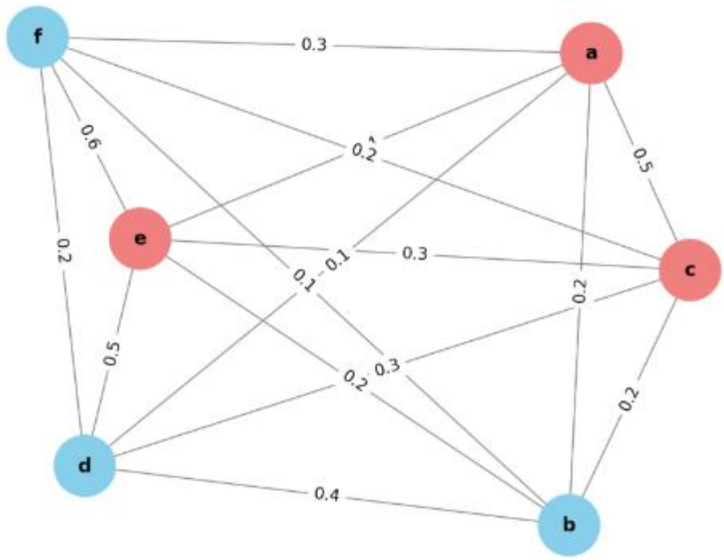

Figure 2. Fuzzy graph G=(V,σ) with vertex set V={a,b,c,d,e,f}. Edge weights represent fuzzy adjacency values σ(u,v)∈ [0,1]

Subadditivity of the k-Integrity Fuzzy Domination Number Under Disjoint Union

Theorem 3

Let $G_1 = (V_1, \sigma_1)$ and $G_2 = (V_2, \sigma_2)$ be two undirected fuzzy graphs with disjoint vertex sets (i.e., $V_1 \cap V_2 = \emptyset$), where the fuzzy adjacency functions $\sigma_1: V_1 \times V_1 \to [0,1]$ and $\sigma_2: V_2 \times V_2 \to [0,1]$ are symmetric, i.e., $\sigma_i(u,v) = \sigma_i(v,u)$ for $i = 1,2$. Let $G = G_1 \cup G_2$ be the disjoint union of G_1 and G_2. Then, for any threshold $k \in \mathbb{R}^+$, the following inequality holds:

$$\gamma_k^f(G) \le \gamma_{k_1}^f(G_1) + \gamma_{k_2}^f(G_2), \text{ for all } k_1, k_2 \in \mathbb{R}^+ \text{such that } k_1 + k_2 = k$$

Proof

Let $D_1 \subseteq V_1$ be a k_1-integrity fuzzy dominating set of G_1, so by definition:

$$\sum_{u \in D_1} \min_{v \in V_1} \sigma_1(u,v) \ge k_1$$

Similarly, let $D_2 \subseteq V_2$ be a k_2-integrity fuzzy dominating set of G_2, such that:

$$\sum_{u \in D_2} \min_{v \in V_2} \sigma_2(u,v) \ge k_2$$

Now define $D = D_1 \cup D_2 \subseteq V_1 \cup V_2 = V$, and note that D is a subset of G. Because the graphs are disjoint, the fuzzy adjacency values from G_1 and G_2 are evaluated independently. Therefore:

$$\sum_{u \in D} \min_{v \in V} \sigma(u,v) = \sum_{u \in D_1} \min_{v \in V_1} \sigma_1(u,v) + \sum_{u \in D_2} \min_{v \in V_2} \sigma_2(u,v) \ge k_1 + k_2 = k$$

Hence, D is a valid k-integrity fuzzy dominating set in G, and its size satisfies:

$$|D| = |D_1| + |D_2| \ge \gamma_{k_1}^f(G_1) + \gamma_{k_2}^f(G_2)$$

Therefore:

$$\gamma_k^f(G) \le \gamma_{k_1}^f(G_1) + \gamma_{k_2}^f(G_2)$$

Example

Let us consider two fuzzy graphs $G_1 = (V_1, \sigma_1)$ and $G_2 = (V_2, \sigma_2)$, defined as follows:

Graph 1: G_1

- $V_1 = \{a, b\}$
- Fuzzy adjacency matrix σ_1 :

$$\sigma_1 = \begin{bmatrix} 0 & 0.6 \\ 0.6 & 0 \end{bmatrix}$$

Compute minimum fuzzy adjacency per vertex:

- $\min_{vCV_1} \sigma_1(a,v) = \min(0,0.6) = 0$
- $\min_{vCV_1} \sigma_1(b,v) = \min(0.6,0) = 0$

To ensure non-zero contribution, assume each vertex has a self-loop of 0.4:

$$\sigma_1 = \begin{bmatrix} 0.4 & 0.6 \\ 0.6 & 0.4 \end{bmatrix}$$

Then:

- $\min_{vCV_1} \sigma_1(a, v) = \min(0.4, 0.6) = 0.4$
- $\min_{vCV_1} \sigma_1(b, v) = 0.4$

Choose $k_1 = 0.8$. Let $D_1 = \{a, b\}$:

$$\sum_{u \in D_1} \min_{v \in V_1} \sigma_1(u, v) = 0.4 + 0.4 = 0.8 \Rightarrow D_1 \text{ is a } k_1\text{-integrity dominating set}$$

$$\Rightarrow \gamma_{k_1}^f(G_1) \leq |D_1| = 2$$

Graph 2: G_2

- $V_2 = \{c, d, e\}$
- Fuzzy adjacency matrix σ_2 :

$$\sigma_2 = \begin{bmatrix} 0.5 & 0.7 & 0 \\ 0.7 & 0.5 & 0.4 \\ 0 & 0.4 & 0.6 \end{bmatrix}$$

Minimum fuzzy adjacency values:

- $\min(\sigma_2(c)) = \min(0.5, 0.7, 0) = 0$
- Again, include 0.4 self-loops to ensure positivity.

Updated:

$$\sigma_2 = \begin{bmatrix} 0.4 & 0.7 & 0 \\ 0.7 & 0.4 & 0.4 \\ 0 & 0.4 & 0.4 \end{bmatrix}$$

Now:

- $\min_{vcV_2} \sigma_2(c, v) = \min(0.4, 0.7, 0) = 0$
- $\min_{vcV_2} \sigma_2(d, v) = \min(0.7, 0.4, 0.4) = 0.4$
- $\min_{v<V_2} \sigma_2(e, v) = \min(0, 0.4, 0.4) = 0$

Take $D_2 = \{d\}$, and let $k_2 = 0.4$:

$$\sum_{u \in D_2} \min_{v \subset V_2} \sigma_2(u, v) = 0.4 \Rightarrow D_2 \text{ is a } k_2\text{-integrity dominating set}$$

$$\Rightarrow \gamma_{k_2}^f(G_2) \leq |D_2| = 1$$

Disjoint Union: $G = G_1 \cup G_2$

Let

- $k = k_1 + k_2 = 0.8 + 0.4 = 1.2$
- $D = D_1 \cup D_2 = \{a, b, d\}$

$$\sum_{w \in D} \min_{v \subset V} \sigma(u, v) = \sum_{u \in D_1} \min_{v \in V_1} \sigma_1(u, v) + \sum_{u \in D_2} \min_{v \subset V_2} \sigma_2(u, v) = 0.8 + 0.4 = 1.2$$

Thus:

- $D \subseteq V_1 \cup V_2$ is a valid k-integrity dominating set in G
- $|D| = 3$, and:

$$\gamma_k^f(G) \leq \gamma_{k_1}^f(G_1) + \gamma_{k_2}^f(G_2') = 2 + 1 = 3$$

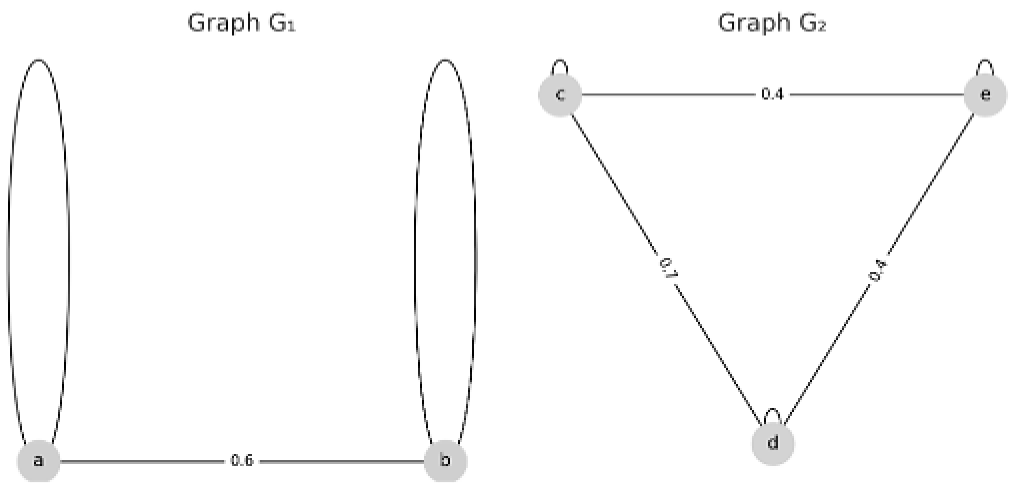

Figure 3. fuzzy graphs $G_1 = (V_1, \sigma_1)$ and $G_2 = (V_2, \sigma_2)$,

CONCLUSION

This paper presents a new concept in fuzzy graph theory called the k-integrity fuzzy domination number, $\gamma_k^I(G)$ which combines the ideas of fuzzy influence and structural resilience into one framework. Unlike traditional fuzzy domination models that focus solely on coverage, the proposed parameter imposes a quantitative threshold condition, requiring the aggregated minimum fuzzy adjacency of the dominating set to meet or exceed a prescribed resilience level k. This improvement takes into account both the unpredictability of fuzzy environments and the necessity for strength in areas like sensor networks, secure communication systems, and social influence analysis. We rigorously develop the theoretical framework through several foundational results. We prove that $\gamma_k^I(G)$ is monotonic in k, establish a computable upper bound based on the minimum fuzzy adjacency, and demonstrate subadditivity under disjoint graph unions.

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