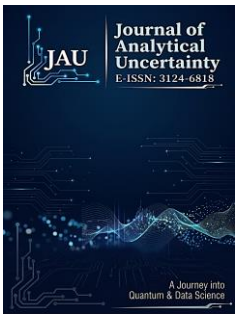
OPEN ACCESS PEER-REVIEWED

JAU Vol.2, No.1, 2026 - Page: 99-106
doi.org/10.63924/jau.v2i1.346
e-ISSN: 3124-6818



Check for updates

A Systematic Analysis of Subsystem Interactions and Failure Propagation in Intuitionistic Fuzzy Graphs

K. Umamaheswari[1*]

[1]Department of Mathematics, Sri Krishna Arts and Science College, Bharathiyar University, Coimbatore, India

*Corresponding author: K. Umamaheswari, Department of Mathematics, Sri Krishna Arts and Science College, Bharathiyar University, Coimbatore, India. Email: umamaheswarik@skasc.ac.in

Abstract

Intuitionistic fuzzy graphs (IFGs) provide a mathematical framework for modelling complex systems characterised by uncertainty, imprecise relationships and incomplete information. Unlike fuzzy graphs, IFGs attach to every vertex and edge a membership degree, a non-membership degree and a hesitation degree. This paper uses complete intuitionistic fuzzy graphs (CIFGs) to analyse how a failure that starts in one part of a system spreads to the others. Each vertex represents a stage of the failure process (a failure state), and each edge represents the interaction through which failure can pass from one stage to another. The membership degree measures how strongly failure propagates, and the non-membership degree measures how strongly it does not. We define the strength of connectedness, strong edges, edge domination and bondage sets for CIFGs, and we give a systematic algorithm for finding a minimum edge dominating set, a minimum bondage set and non-bondage sets. The method is illustrated on a five-state failure chain. In this example the edge between the detected failure and the spreading failure is the dominant propagation channel, every edge is strong, the edge domination number is 0.7, and the minimum bondage set consists of the four edges incident to the system-level failure state (total cardinality 1.2). The results give a theoretical basis for reliability assessment, risk analysis, fault diagnosis and resilient design of interconnected systems.

Keywords: Intuitionistic Fuzzy Graph, Complete Intuitionistic Fuzzy Graph, Subsystem Interaction, Failure Propagation, Cascading Failure, Edge Domination, Bondage Set, System Reliability, Vulnerability Analysis

Introduction

Complex systems are composed of interconnected subsystems that interact through functional, structural or information-based relationships [2]. The performance of the whole system therefore depends not only on the reliability of the individual subsystems but also on the nature and strength of their interactions. A failure in one subsystem may affect the subsystems connected to it and spread through the network, which leads to degraded performance or cascading failure [3]. Identifying the critical subsystems, the vulnerable interactions and the main failure-propagation paths is thus an important problem in reliability analysis, risk assessment and resilient system design.

Atanassov [2] introduced intuitionistic fuzzy sets, which extend fuzzy sets by assigning to each element a membership degree, a non-membership degree and a hesitation degree. Intuitionistic fuzzy graphs (IFGs), built on this concept, represent uncertain and imprecise

Copyright: © 2026 by the author(s). This is an open access article distributed under the CC BY-SA 4.0 license

Received: March 04, 2026 - Accepted: November 20, 2026 - Published online: November 22, 2026

relationships in networks. In an IFG, every vertex and every edge has a membership and a non-membership value, and the remaining hesitation degree reflects the lack of available information.

These features are valuable in failure analysis, because dependencies between subsystems are rarely known with certainty. The likelihood or severity of failure propagation between two subsystems depends on incomplete observations, expert judgement and operating conditions. An IFG can represent such interactions more faithfully than a crisp or fuzzy graph.

The aim of this paper is to give a mathematical framework for analysing failure propagation in uncertain interconnected systems. The main contributions are as follows. First, we define the notions needed for the analysis (complete intuitionistic fuzzy graph, strength of connectedness, strong edge, edge cardinality, edge dominating set and bondage set) and we state precisely what each one means for failure propagation. Second, we prove that every edge of a complete intuitionistic fuzzy graph is strong. Third, we give an algorithm that finds minimum edge dominating sets, minimum bondage sets and non-bondage sets. Fourth, we apply the algorithm to a five-state failure chain and interpret the results.

The remainder of the paper is organised as follows. Section 2 reviews related work. Section 3 gives the definitions and notation. Section 4 presents the algorithm. Section 5 describes the application, and Section 6 discusses the results. Section 7 concludes the paper.

Literature review

Fuzzy graphs were introduced by Rosenfeld [9], and intuitionistic fuzzy sets by Atanassov [2]. Standard references for classical graph theory, which we use for the basic notions of paths, adjacency and subgraphs, are the books by Chartrand et al. [3] and Diestel [4].

Mathew et al. [5], in their book *Fuzzy Graph Theory*, give a systematic treatment of graph theory in the fuzzy setting, where vertices and edges have degrees of membership instead of being strictly present or absent. The book develops the fundamental concepts of fuzzy graphs, including connectivity and strength of connectedness, and examines their structures and applications. Akram and Zafar [1], in *Hybrid Soft Computing Models Applied to Graph Theory*, study the combination of soft computing techniques, such as fuzzy sets and soft sets, with graph-theoretical concepts, in order to treat problems involving uncertainty, vagueness and imprecise information.

Naeem et al. [7] investigate connectivity indices of intuitionistic fuzzy graphs and their applications in internet routing and transport network flow. Their indices use the membership and non-membership degrees to give quantitative measures of the strength and reliability of connections in a network. Mordeson et al. [6], in *Fuzzy Graph Theory: Applications to Global Problems*, use fuzzy graph theory to model and solve real-world problems with uncertainty and incomplete information, and they show how such models support the analysis of complex systems and decision-making.

Rashmanlou and Borzooei [8], in *Intuitionistic Fuzzy Graphs: Theory and Applications*, give a comprehensive treatment of IFGs, in which membership and non-membership degrees describe both vertices and edges. Talebi et al. [11] propose a new concept of an intuitionistic fuzzy graph with applications, and Shao et al. [10] introduce new concepts in intuitionistic fuzzy graphs and apply them to water supplier systems. More recently, Talebi and Rashmanlou [12], in *Advanced Concepts in Intuitionistic Fuzzy Graph Theory*, present advanced structural concepts, properties and operations for IFGs, and they point to applications in decision-making, network analysis and optimisation.

The works reviewed above develop the theory of fuzzy and intuitionistic fuzzy graphs and their connectivity. To the best of our knowledge, they do not directly treat subsystem interaction and failure propagation through edge domination and bondage sets in complete intuitionistic fuzzy graphs. This paper addresses that gap.

Preliminaries and Notation

Throughout, G = (V, E) is a finite graph with vertex set V and edge set E. We write uv for the edge joining the vertices u and v. In the application, a vertex is a stage of the failure process and an edge is an interaction through which failure can pass between two stages.

Definition 1 (intuitionistic fuzzy graph). An *intuitionistic fuzzy graph* (IFG) is a pair G = (V, E) with functions $\mu_1, \nu_1: V \to [0, 1]$ and $\mu_2, \nu_2: E \to [0, 1]$ such that $0 \le \mu_1(v) + \nu_1(v) \le 1$ for every vertex v, and for every edge uv,

$$\mu_2(uv) \le \min\{\mu_1(u), \mu_1(v)\}, \quad \nu_2(uv) \le \max\{\nu_1(u), \nu_1(v)\}, \quad 0 \le \mu_2(uv) + \nu_2(uv) \le 1. \quad (1)$$

The numbers $\mu_1(v)$ and $\nu_1(v)$ are the membership and non-membership degrees of the vertex v, and $\mu_2(uv)$ and $\nu_2(uv)$ are those of the edge uv. The hesitation degrees are $\pi_1(v) = 1 - \mu_1(v) - \nu_1(v)$ and $\pi_2(uv) = 1 - \mu_2(uv) - \nu_2(uv)$. In this paper, the membership degree is read as the *degree of propagation* (how strongly failure is present or passes on) and the non-membership degree as the *degree of non-propagation*.

Definition 2 (complete intuitionistic fuzzy graph). An IFG is a *complete intuitionistic fuzzy graph* (CIFG) if every two distinct vertices u and v are joined by an edge and the inequalities in (1) hold with equality for membership and non-membership, that is, $\mu_2(uv) = \min\{\mu_1(u), \mu_1(v)\}$ and $\nu_2(uv) = \max\{\nu_1(u), \nu_1(v)\}$. In failure analysis, a CIFG describes a system in which any two stages can interact directly, and in which an interaction is never more severe than the weaker of the two stages it connects.

Definition 3 (strength of connectedness). A *path* from u to v is a sequence of distinct vertices $u = x_0, x_1, \ldots, x_k = v$ in which consecutive vertices are joined by edges. The membership strength of a path is the smallest edge membership on it, and its non-membership strength is the largest edge non-membership on it. The *strength of connectedness* between u and v in G is the pair $(\mathrm{CONN}_\mu(u, v), \mathrm{CONN}_\nu(u, v))$, where

$$\mathrm{CONN}_\mu(u, v) = \text{max over all paths P from u to v of } \min_{xy \in P} \mu_2(xy), \quad (2)$$

$$\mathrm{CONN}_\nu(u, v) = \text{min over all paths P from u to v of } \max_{xy \in P} \nu_2(xy). \quad (3)$$

Thus $\mathrm{CONN}_\mu(u, v)$ is the propagation degree of the best route from u to v (the route that is as strong as possible at its weakest link), and $\mathrm{CONN}_\nu(u, v)$ is the corresponding non-propagation degree. We write $\mathrm{CONN}_\mu(G)$ and $\mathrm{CONN}_\nu(G)$ when the graph must be named.

Definition 4 (strong edge). An edge uv of G is *strong* if no route between u and v is better than the edge itself, that is,

$$\mu_2(uv) \ge \mathrm{CONN}_\mu(G)(u, v) \quad \text{and} \quad \nu_2(uv) \le \mathrm{CONN}_\nu(G)(u, v). \quad (4)$$

Because the edge uv is itself a path from u to v, we always have $\mathrm{CONN}_\mu(u, v) \ge \mu_2(uv)$ and $\mathrm{CONN}_\nu(u, v) \le \nu_2(uv)$. Hence (4) holds exactly when $\mu_2(uv) = \mathrm{CONN}_\mu(u, v)$ and $\nu_2(uv) = \mathrm{CONN}_\nu(u, v)$. An edge that is not strong is called *weak*. A stronger route can bypass a weak edge, whereas a strong edge is the most effective channel between its end vertices.

Proposition 1. Every edge of a complete intuitionistic fuzzy graph is strong.

Proof. Let uv be an edge and let P be any path from u to v. The first edge of P contains u and the last edge of P contains v. By the definition of a CIFG, an edge containing a vertex x has membership at most $\mu_1(x)$ and non-membership at least $\nu_1(x)$. Hence the smallest membership on P is at most $\min\{\mu_1(u), \mu_1(v)\} = \mu_2(uv)$, and the largest non-membership on P is at least $\max\{\nu_1(u), \nu_1(v)\} = \nu_2(uv)$. Taking the best path gives $\mathrm{CONN}_\mu(u, v) \le \mu_2(uv)$ and $\mathrm{CONN}_\nu(u, v) \ge \nu_2(uv)$, which is (4).

Definition 5 (cardinality). The *cardinality* of an edge e is $c(e) = (1 + \mu_2(e) - \nu_2(e)) / 2$, which is the scalar cardinality commonly used for intuitionistic fuzzy sets. For a set S of edges, c(S) is the sum of c(e) over $e \in S$, and $|S|$ denotes the number of edges in S. A larger cardinality means a stronger propagation tendency.

Definition 6 (edge dominating set). Two edges are *adjacent* if they share a vertex. An edge f is a *strong neighbour* of an edge e if f is adjacent to e and f is strong. A set $D \subseteq E$ is an *edge dominating set* of G if every edge in $E - D$ has at least one strong neighbour in D. The *edge domination number* $\gamma'(G)$ is the minimum of c(D) over all edge dominating sets D, and a set attaining this minimum is a *minimum edge dominating set*. In failure analysis, an edge dominating set is a collection of interactions that touches, through strong links, every other interaction in the system, and hence is a natural set of interactions to monitor or to protect.

Definition 7 (bondage and non-bondage sets). For $B \subseteq E$, let $G - B$ be the graph with the same vertices and with edge set $E - B$, strong edges are recomputed in $G - B$. A set $B \ne E$ is a *bondage set* of G if $\gamma'(G - B) > \gamma'(G)$, otherwise B is a *non-bondage set*. The *bondage number* b(G) is the minimum of c(B) over all bondage sets B, and a set attaining it is a *minimum bondage*

set. A bondage set is therefore a set of interactions whose loss makes the system strictly more expensive to cover.

Methods

This section gives the procedure for finding the edge dominating sets, the bondage sets and the non-bondage sets of a complete intuitionistic fuzzy graph G = (V, E).

Step 1. Let G = (V, E) be a CIFG. Compute the cardinality c(e) of every edge e ∈ E (Definition 5).

Step 2. Compute the strength of connectedness ($CONN_\mu(u, v)$, $CONN_\nu(u, v)$) for every edge uv using (2) and (3).

Step 3. Determine the strong edges, that is, the edges satisfying condition (4). By Proposition 1, all edges of a CIFG are strong, so this step serves as a check for CIFGs. It is essential for the subgraphs G – B in Step 5, which need not be complete.

Step 4. Find the minimum edge dominating sets and the edge domination number $\gamma'(G)$ (Definition 6).

Step 5. List the non-empty sets $B \subset E$, $B \neq E$, in non-decreasing order of c(B), ties are broken arbitrarily. For each B, form G – B, recompute its strong edges as in Step 3, compute $\gamma'(G - B)$ as in Step 4, and compare it with $\gamma'(G)$. If $\gamma'(G - B) > \gamma'(G)$, then B is a bondage set, otherwise B is a non-bondage set. When all the edges considered are strong, sets of smaller cardinality are examined first.

Step 6. The first bondage set found in Step 5 has the smallest total cardinality, so it is a minimum bondage set, and its cardinality is the bondage number b(G). All bondage sets of the same cardinality are minimum bondage sets. The remaining sets are the non-bondage sets.

The enumeration in Step 5 examines up to $2^{|E|} - 2$ subsets, so the procedure is exact but practical only for small graphs. For larger networks, one may restrict B to a given maximum size or use a heuristic that removes edges of smallest cardinality first. In the example in Section 5, |E| = 10, and all 1022 subsets were examined.

Application to Failure Propagation in a Five-State System

The model

Consider a system whose failure develops through five stages. Each vertex of G represents one stage of the failure process, together with the subsystem in which it occurs, that is, a vertex is a failure *state* of the system. The five states, with the acronyms used in this paper, are listed in Table 1.

The distinction between IF and DF needs explanation. The initial failure (IF) is the moment at which a fault first occurs, when no earlier failure has taken place in the system, at that moment the fault may still be latent, that is, not observed. The failure becomes a detected or propagated failure (DF) only when monitoring observes it or when it passes to an adjacent subsystem. The two states are kept apart because they carry different degrees: an initial fault has the degrees (0.4, 0.6), while a detected or propagating failure has (0.8, 0.2), because a failure that has become observable or has begun to spread is much more likely to be severe than a fault at its point of origin.

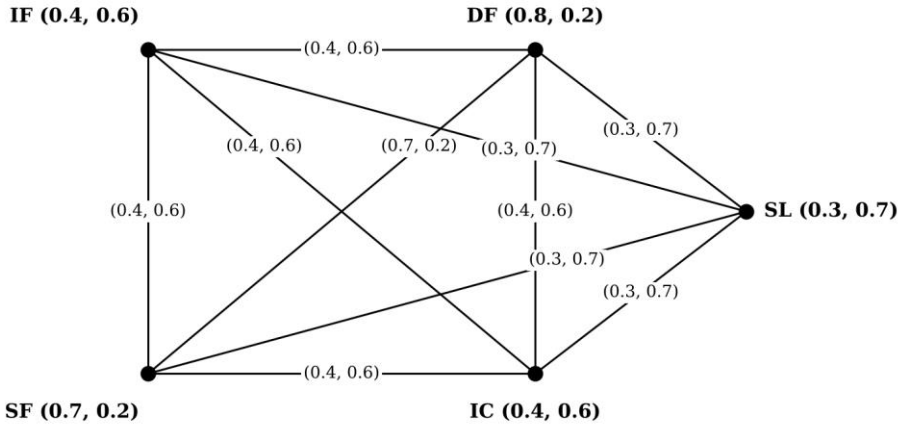
The degrees in this example are illustrative values chosen to demonstrate the method. In a practical study they would be obtained from expert judgement or from failure records. For a vertex v, $\mu_1(v)$ is the degree to which failure in state v is severe or propagates, and $\nu_1(v)$ is the degree to which it is not. For an edge uv, $\mu_2(uv)$ and $\nu_2(uv)$ are the degrees to which failure does and does not pass between the two states. The graph is complete, so every two states interact directly, and the edge degrees follow Definition 2 (minimum of the membership degrees and maximum of the non-membership degrees of the end vertices).

Table 1: Vertices (failure states) of the graph G, with their acronyms and degrees.

Acronym	Failure state	Short description	μ_1	ν_1	π_1
IF	Initial failure	Fault first occurs, may be latent	0.4	0.6	0.0

DF	Detected or propagated failure	Fault observed or passed on	0.8	0.2	0.0
IC	Intermediate-component failure	Intermediate component fails	0.4	0.6	0.0
SF	Spreading failure	Failure spreads further	0.7	0.2	0.1
SL	System-level failure	Final failure of the system	0.3	0.7	0.0

Figure 1: The complete intuitionistic fuzzy graph G of the five failure states. Each vertex and each edge is labelled with its pair (μ, ν).



Strength of connectedness and strong edges

We apply Steps 1 to 3 of the algorithm. Table 2 gives, for each of the ten edges, its degrees, its strength of connectedness computed from (2) and (3) over all paths of G, its status and its cardinality.

Table 2: Edges (interactions between two failure states): degrees, strength of connectedness, status and cardinality.

Edge	μ_2	ν_2	$CONN_\mu$	$CONN_\nu$	Strong	Cardinality c(e)
IF–DF	0.4	0.6	0.4	0.6	Yes	0.40
IF–IC	0.4	0.6	0.4	0.6	Yes	0.40
IF–SF	0.4	0.6	0.4	0.6	Yes	0.40
IF–SL	0.3	0.7	0.3	0.7	Yes	0.30
DF–IC	0.4	0.6	0.4	0.6	Yes	0.40
DF–SF	0.7	0.2	0.7	0.2	Yes	0.75
DF–SL	0.3	0.7	0.3	0.7	Yes	0.30
IC–SF	0.4	0.6	0.4	0.6	Yes	0.40
IC–SL	0.3	0.7	0.3	0.7	Yes	0.30
SF–SL	0.3	0.7	0.3	0.7	Yes	0.30

For every edge uv, the strength of connectedness equals the degrees of uv itself, so all ten edges are strong, which agrees with Proposition 1. For example, for the edge IF–SL the paths from IF to SL include IF–DF–SL, IF–DF–SF–SL and IF–SL, each of them contains an edge incident to SL, so each has membership strength at most 0.3 and non-membership strength at least 0.7, and the direct edge attains (0.3, 0.7).

Edge dominating sets and bondage sets

Steps 4 to 6 were carried out by exhaustive enumeration. Because G has five vertices and all edges are strong, any two edges without a common vertex form an edge dominating set: the four vertices they cover are incident to them, and every other edge shares a vertex with one of the two. The edge domination number is therefore the smallest total cardinality of two disjoint edges, namely $\gamma'(G) = 0.3 + 0.4 = 0.7$. There are ten minimum edge dominating sets, and each consists of one

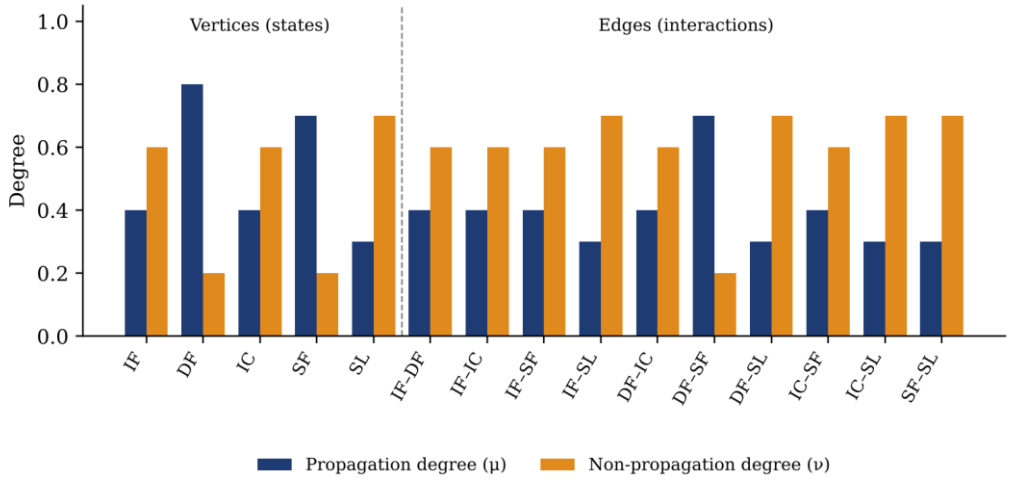
edge incident to SL (cardinality 0.3) together with one disjoint edge of cardinality 0.4, for example {IF–DF, IC–SL} and {IF–SL, DF–IC}. None of them contains the edge DF–SF (cardinality 0.75).

For the bondage sets, all 1022 non-empty proper subsets B of E were examined. Removing any set of at most three edges does not increase the domination number, so no set with at most three edges is a bondage set. Exactly 17 of the 1022 subsets are bondage sets. The one with the smallest total cardinality is B = {IF–SL, DF–SL, IC–SL, SF–SL}, the four edges incident to SL, with c(B) = 1.2. After the removal of B, the vertex SL is isolated, the remaining graph is a complete graph on four vertices, and its edge domination number is 0.4 + 0.4 = 0.8 > 0.7. Hence b(G) = 1.2 and B is the unique minimum bondage set. The other 1005 subsets are non-bondage sets, in particular, every single edge is a non-bondage set.

Results and Discussion

Figure 2 summarises the degrees of the five failure states and of the ten interactions. The results can be interpreted as follows.

Figure 2: Propagation degree (μ) and non-propagation degree (ν) of the failure states (vertices) and of the interactions (edges).



Failure states. The detected or propagated failure DF has the highest propagation degree (0.8, with non-propagation degree 0.2), followed by the spreading failure SF (0.7 and 0.2). The initial failure IF and the intermediate-component failure IC both have the degrees (0.4, 0.6), and the system-level failure SL has the lowest propagation degree (0.3, with 0.7 for non-propagation). SF is the only state with a non-zero hesitation degree (0.1), so the available information about SF is the least complete, the other four states are fully specified ($\mu_1 + \nu_1 = 1$).

Interactions. The edge DF–SF is the dominant propagation channel: it is the only edge with a propagation degree above 0.4 (degrees (0.7, 0.2), cardinality 0.75). All edges incident to SL have a propagation degree of at most 0.3. This is a consequence of the model, since the weaker end vertex limits the degrees of an edge in a CIFG, thus, the interactions that lead to the system-level failure are limited by the low propagation degree of SL itself.

Strong edges. Since every edge is strong, no alternative route between two states is more favourable to propagation than the direct interaction. Consequently, in this example, the strength of connectedness between any two states is determined by the direct edge, and detailed path analysis does not change the picture.

Edge domination. The edge domination number is $\gamma'(G) = 0.7$. Every minimum edge dominating set pairs one edge incident to SL with one disjoint edge of cardinality 0.4. In practical terms, covering all interactions through strong links requires monitoring or protecting only two disjoint interactions, and the cheapest choices avoid the high-cardinality edge DF–SF.

Bondage. The bondage number is b(G) = 1.2. No set of one, two or three interactions can be removed in a way that increases the domination number, so the monitoring structure of this system is robust to isolated link losses. Only the loss of all four interactions of the system-level state SL changes the domination number, from 0.7 to 0.8. The interactions of SL are therefore

the most influential from the point of view of bondage, even though they have the smallest cardinalities.

Limitations. The degrees used here are illustrative, and the conclusions depend on them. The enumeration in Step 5 is exponential in the number of edges. The example is a CIFG, so the strong-edge condition is automatically satisfied for G, it becomes informative for the subgraphs G – B and for non-complete IFGs.

Conclusion

This paper presented a framework based on complete intuitionistic fuzzy graphs for analysing subsystem interactions and failure propagation. We defined the strength of connectedness, strong edges, edge cardinality, edge dominating sets and bondage sets in this setting, proved that all edges of a complete intuitionistic fuzzy graph are strong, and gave an algorithm for finding minimum edge dominating sets, minimum bondage sets and non-bondage sets. In a five-state example, the edge between the detected failure and the spreading failure was identified as the dominant propagation channel, the edge domination number was 0.7, and the minimum bondage set was the set of four edges incident to the system-level failure state, with bondage number 1.2. Future work includes applying the method to real failure data, treating non-complete IFGs in which weak edges occur, comparing other cardinality measures, and developing more efficient algorithms for large networks.

Ethics approval

Not required.

Acknowledgments

No acknowledgements.

Competing interests

All the authors declare that there are no conflicts of interest.

Funding

This study received no external funding.

Underlying data

Derived data supporting the findings of this study are available in article.

CRediT authorship contribution statement

K. Umamaheswari: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Project administration, Supervision.

Declaration of artificial intelligence use

In preparing this work, the authors employed artificial intelligence (Gemini) (AI)-assisted tools for language editing and the refinement of selected graphical representations. Following the use of these tools, the authors critically evaluated and verified all content to ensure the scientific rigor and reliability of the study. All conceptual decisions, mathematical derivations, analytical procedures, interpretations, and conclusions remain exclusively those of the author.

How to cite

Umamaheswari, K. (2026). A Systematic Analysis of Subsystem Interactions and Failure Propagation in Intuitionistic Fuzzy Graphs. *Journal of Analytical Uncertainty*, *2*(1), 99–106. https://doi.org/10.63924/jau.v2i1.346

References

[1] Akram, M., & Zafar, F. (2020). Hybrid soft computing models applied to graph theory. Springer.

[2] Atanassov, K. T. (1986). Intuitionistic fuzzy sets. Fuzzy Sets and Systems, 20(1), 87–96.

[3] Chartrand, G., Jordon, H., Vatter, V., & Zhang, P. (2024). Graphs & digraphs (7th ed.). Chapman & Hall/CRC.

[4] Diestel, R. (2025). Graph theory (6th ed.). Springer.

[5] Mathew, S., Mordeson, J. N., & Malik, D. S. (2018). Fuzzy graph theory. Springer.

[6] Mordeson, J. N., Mathew, S., & Gayathri, G. (2023). Fuzzy graph theory: Applications to global problems. Springer.

[7] Naeem, T., Gumaei, A., Jamil, M. K., Alsanad, A., & Ullah, K. (2021). Connectivity indices of intuitionistic fuzzy graphs and their applications in internet routing and transport network flow. Mathematical Problems in Engineering, 2021, Article 4156879. https://doi.org/10.1155/2021/4156879

[8] Rashmanlou, H., & Borzooei, R. A. (2024). Intuitionistic fuzzy graphs: Theory and applications. De Gruyter.

[9] Rosenfeld, A. (1975). Fuzzy graphs. In L. A. Zadeh, K. S. Fu, & M. Shimura (Eds.), Fuzzy sets and their applications to cognitive and decision processes (pp. 77–95). Academic Press.

[10] Shao, Z., Kosari, S., Rashmanlou, H., & Shoaib, M. (2020). New concepts in intuitionistic fuzzy graph with application in water supplier systems. Mathematics, 8(8), 1241. https://doi.org/10.3390/math8081241

[11] Talebi, A. A., Kacprzyk, J., Rashmanlou, H., & Sadati, S. H. (2020). A new concept of an intuitionistic fuzzy graph with applications. Journal of Multiple-Valued Logic & Soft Computing, 35(5–6), 431–450.

[12] Talebi, A. A., & Rashmanlou, H. (2025). Advanced concepts in intuitionistic fuzzy graph theory. Springer.