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Critical Path Method & Project Evaluation and Review Technique: A Neutrosophic Review

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Abstract. Fuzzy, intuitionistic, and neutrosophic sets are the primary focus of the review investigation under the extension concepts. The significance and use of triangular shape for data representation are investigated. For modelling and expressing ambiguous or complex data, the triangle shape is a useful tool due to its simplicity and computational efficiency. Further study involves the tool of the operations research technique i.e., Network Analysis that helps in implementing and developing using the fuzzy extension principle. Critical Path Method (CPM) & Project Evaluation and Review Technique (PERT) plays a major part in the field of network in various decision-making scenarios using the real-life applications. In this comprehensive study, the insights of understanding extended fuzzy using the CPM/PERT under various applications are reviewed and analyzed for the future advancements in making more accurate and optimum results.

Keywords: Network Analysis; Critical Path Method (CPM); Project Evaluation and Review Technique (PERT); Uncertainty; Extended Fuzzy Principle

1. **Introduction**

Uncertainty plays a leading role in various fields of modern upgrowth in science and technology, due to ruling world of vague and ambiguity. Followed by which, zadeh introduced the fuzzy concept in 1965, uncertainty theory has risen significantly [1], many researchers from the distinctive domains have worked and executed the uncertainty study in various fields such as science and technology, medical experimental, social media, financial mathematics, ecology etc. Fuzzy sets play a standard role in many technical problems. However, there is an essential issue regarding to relate or use the idea of impreciseness in our computational mathematical modelling. From which a few years later, Chang and Zadeh [2] gave the outline sketch of fuzzy development in the idea of fuzzy sets and formative numbers. Many experts in the subject have proposed various ways to describe it, offered suggestions such as the triangle fuzzy number [3], and shared their views on the best way to deal with uncertainty.

In real-life, environments often express their preferences in more complicated ways, where the expression involves the degree of belief and degree of disbelief towards a certain statement, as if these degrees overlap. In this regard, Krassimir Atanassov came up with the idea of an Intuitionistic fuzzy number (IFN) [4], involving both membership and non-membership belongingness. Following this, the fuzzy triangle IFN shape [5] was created and used in a specific area of mathematics. In furthermore study, Inter-valued IFN [6] study was manifested as it the extension work of IFN. The previous research led to the conclusion that the combined membership and non-membership functions cannot exceed to 1. But in real life, it's not always feasible to stick to the rules and provide under restriction. As an example, if someone says they are 0.8% satisfied the other 0.4% termed as dissatisfied. Therefore, to such situations, IFS theory cannot be handled. To get around this, Yager [7] modified the IFS criteria by squaring the sum of the related sets, corresponding to be Pythagorean fuzzy sets (PFS). The advancement of uncertainty theory, particularly fuzzy set theory and its extensions like IFS and PFS, features the continuous effort to model and interpret the complexity of real-world phenomena more accurately. These advancements reflect on understanding the real-life situations often exhibit degrees of uncertainty that traditional binary logic cannot be captured, as to get a brief view Figure.1 can be addressed for the flowchart of different uncertain parameters.

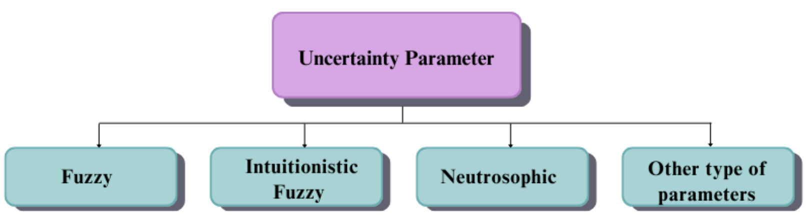

FIGURE 1. Flowchart for different uncertain parameter

Additionally, multiple researchers have put the theories into action, by creating and improving numerous approaches, and offered several recommendations for using the uncertainty philosophy. The lack of a representation of the unclear parameter leads the literature to address various ideas for classifying these characteristics. Different applications have granted decision-making authority to address such difficulty. Smarandache has created an IFN extension for the previously anticipated setting, termed as the Neutrosophic set (NS) [8]. It determines the truthiness (T), indeterminacy (I), or falsity (F) of each element using membership functions.

Contrarily, NS vary from IFN by sum of truth, indeterminacy, and falsity can be equal or less than equal to 3 on any real number between the interval [0,1]. Considering intuitionistic fuzzy set theories and fuzzy set theories with fuzzy boundaries, where the membership value is always between 0 and 1. Decision making (DM) problems and mathematical modelling are two of its most common modern applications. An increasingly effective tool for tackling complicated problems was created by Wang et.al., [9] via ongoing study; it is the enhanced perception of a single-typed neutrosophic set. In addition, Chakraborty et.al., 10 classified the concept of triangular neutrosophic. Further, the implementation of basic information about uncertain parameters, differing from each other using the concept of uncertainty using some definitions, flowcharts, and diagrams are shown in further sections.

1.1. *Verbal phase related to uncertainty*

In the daily life, researchers often focus on the point of establishing a logical relationship in the state of uncertainty concept in the real-world scenario with the idea of verbal phase for better understanding the concept. In this phenomenon, using the idea mentioned, the construction for such raised questioned can be explained using the example mentioned below:

Example: To maintain a democratic approach while forming the committee, for employing a vote system that incorporates the sentiments, hopes, feeling, ethics and dreams of the group members. An expressed statement describing the amount of support, opposition, or neutrality for the prospective committee member is used by each member to indicate their choice to capture the uncertain and inherent information in decision-making environment was captured by Table 1.

Table 1. Verbal phrases for different uncertain parameters

Uncertainty	**Verbal**	**Description**
Crisp Parameter	Support/Oppose	Members expressing the response in the form of binary logic indicating either support as 1 or oppose as 0.
Fuzzy Parameter	Degree of Support	Members expressing the response indicating their fully support or completely Non-support.

Continued on next page

Table 1 – Continued from previous page

Uncertainty	**Verbal**	**Description**
Intuitionistic Fuzzy	Support and Non-Support	Members expressing their support and non-support levels separately, using the level of degrees of uncertainty.
Neutrosophic	Support, Neutral, Non-Support	In NS, the members expressing in three distinct stances, in capturing the complexity of human opinion, including indecisiveness and neutrality.

1.2. *Some basic differences between some uncertain parameters*

Various kinds of sets having expression with different strengths and weaknesses that deals with the real-world challenges, can be seen in the Table 2 and better visualization is presented in Figure 2.

TABLE 2. Differences between uncertain parameters

Various types of sets	**Advantages**	**Limitations**
Crisp Sets	Can correctly decide without any hesitation	Dealing with the information having uncertainty
Fuzzy sets	Can correctly describe and define uncertain	Cannot define the non-membership degree having the uncertain Information
Intuitionistic Fuzzy set	Can define the information having non-membership (NMS) and membership (MS) degree function	The addition of MS and NMS degree obtains above 1

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Table 2 – Continued from previous page

Various types of sets	**Advantages**	**Limitations**
Neutrosophic	Dealing with indeterminacy and getting the optimum result	Interval data type cannot be handled

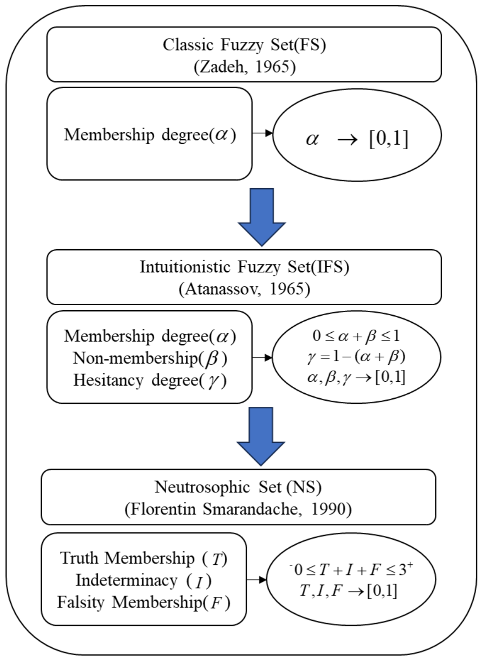
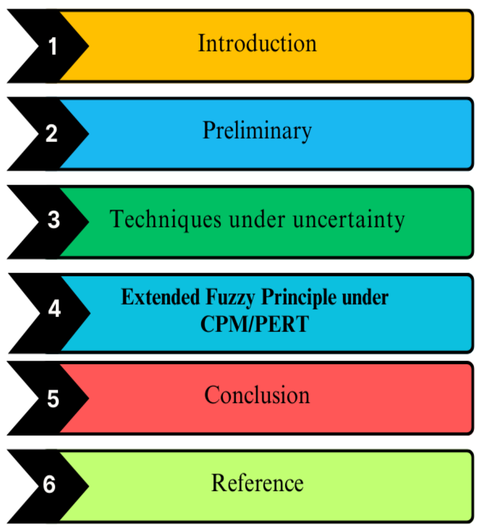


FIGURE 2. The development of NS and the extension of the classical fuzzy sets

Project scheduling strategies like Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) are the major emphasis of the study. The network analysis fields of project management have benefited greatly from these two well-known approaches because of the helpful information they provide on timeframes, resource allocation, and risk analysis, as they are the integral part of project planning, scheduling, and controlling. To find the best possible time or solution relies heavily on CPM's primary focus on finding the route, which is comprised of interdependent actions [11]. A single time factor is used to anticipate the long route duration using CPM [12]. But in actual projects, these assumptions don't take unexpectedness and variety into consideration. One way to deal with these assumptions is Project Evaluation and Review Technique (PERT), as it recognizes the nature of possible activity periods to be unknown [13]. It considers these unknowns and help in making the project to find more optimality. Project managers may maximize performance by organizing tasks using CPM and taking uncertainties into account using PERT. Management of project hazards, resource allocation, and overall project length may all be improved with the use of these methods. Combining CPM with PERT has changed the game for project management, allowing businesses to make better use of their resources and, in the end, discover better solutions. While most cases display activity times accurately, in deterministic assumptions. But, when dealing with uncertain or imprecise data, to predict and analyze potential outcomes by employing numerical representations of the data is critical. To involve uncertainty and imprecision in project parameters more realistically, the use of triangle shapes delves into CPM/PERT act as the crucial role in task durations and activity periods. Several studies have explored cases where activity times in a project are approximately known and can be suitably represented by sets rather, than precise numbers [14, 15].

1.3. *Structure of the paper*

The article is developed as follows:



2. Mathematical Preliminary

Some preliminary concepts of fuzzy sets and fuzzy numbers are discussed Buckley [16], Dubois and Prade [17], Atanassov [18], Li [19], Subas [20], Kaufmann and Gupta [21], Klir and Yuan [22], and Zadeh [23]. The basic definitions and notations below will be used throughout the paper.

Definition 2.1. The set $\widetilde{f}$ is illustrated as $\widetilde{f} = \left\{\left(\psi, \mu_{\widetilde{f}}(\psi)\right) : \psi \in f, \mu_{\widetilde{f}}(\psi) \in [0,1]\right\}$ is often represented by the paired set $\left(\psi, \mu_{\widetilde{f}}(\psi)\right)$, here $\psi \in f$ termed as crisp $\mu_{\widetilde{f}}(\psi) \in [0,1]$; such that $0 \leq \mu_{\widetilde{f}}(\psi) \leq 1$, $\widetilde{f}$ represents fuzzy set.

Definition 2.2. In the fuzzy set, $\widetilde{f}$ be the fuzzy number on the real line R that satisfies the normality condition and the convexity condition.

Definition 2.3. The triangular fuzzy number $(\widetilde{tfn})$ be the fuzzy number with a linear piecewise membership function $\mu_{\widetilde{tfn}}(\psi)$ is described as follows:

$$\mu_{\widetilde{tfn}}(\psi)=\begin{cases}\frac{\psi-tfn_1}{tfn_2-tfn_1}, & tfn_1\le\psi\le tfn_2\\ 1, & \psi=tfn_2\\ \frac{tfn_3-\psi}{tfn_3-tfn_2}, & tfn_2\le\psi\le tfn_3\\ 0, & \text{Otherwise.}\end{cases}$$

Further, TFN can be represented as an ordered triplet $\widetilde{tfn}=(tfn_1,tfn_2,tfn_3)$ and below the diagrammatic view of triangle fuzzy number:

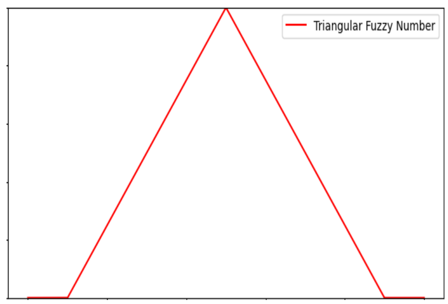


Figure 3:Triangular Fuzzy Number

Definition 2.4. A set $\widetilde{IFS}$, denoted as $\widetilde{IFS}=\{\langle\alpha;[\tau(\alpha),\gamma(\alpha)]\rangle:\alpha\in\psi\}$ may be visually shown as a membership degree in which $\tau(\alpha),\gamma(\alpha):\psi\to[0,1]$, as truth be $\tau(\alpha)$ and false be $\gamma(\alpha)$ the membership degree. The condition for the set $\tau(\alpha),\gamma(\alpha)$ to satisfy $0\le\tau(\alpha)+\gamma(\alpha)\le 1$.

Definition 2.5. The Triangular Intuitionistic fuzzy number $(\widetilde{TIF})$ is presented in Figure 3 termed as intuitionistic fuzzy set in R with the following membership $\lambda_{\widetilde{TIF}}(\psi)$ and non-membership function $\upsilon_{\widetilde{TIF}}(\psi)$ as follows:

$$\lambda_{\widetilde{tif}}(\psi)=\begin{cases}\frac{\psi-tif_1}{tif_2-tif_1}, & tif_1\le\psi\le tif_2\\ \frac{tif_3-\psi}{tif_3-tif_2}, & tif_2\le\psi\le tif_3\\ 0, & \text{Otherwise.}\end{cases}\quad \upsilon_{\widetilde{TIF}}(\psi)=\begin{cases}\frac{tif_1-\psi}{tif_2-tif_1{}'}, & tif_1{}'\le\psi\le tif_2\\ \frac{\psi-tif_2}{tif_3{}'-tif_2}, & tif_2\le\psi\le tif_3{}'\\ 1, & \text{Otherwise.}\end{cases}$$

Further, TIF can be represented as $\widetilde{tif}=(tif_1{}',tif_1,tif_2,tif_3,tif_3{}')$, where $tif_1{}'<tif_1<tif_2<tif_3<tif_3{}'$ and $\lambda_{\widetilde{tif}}(\psi),\upsilon_{\widetilde{tif}}(\psi)\le 0.5$ for $\lambda_{\widetilde{tif}}(\psi)=\upsilon_{\widetilde{tif}}(\psi)\ \forall\ \psi\in$ R.

Definition 2.6. The universal set ψ ,denoted by $(neu)^N$ if it satisfies the condition, is considered a neutrosophic number $(neu)^N=\left\{\left\langle\alpha;[\lambda_{(neu)^N}(\alpha),\beta_{(neu)^N}(\alpha),\gamma_{(neu)^N}(\alpha)]\right\rangle:\alpha\in\psi\right\}$, where $\lambda_{(neu)^N}(\alpha):\psi\to[0,1]$,$\beta_{(neu)^N}(\alpha):\psi\to[0,1]$ and $\gamma_{(neu)^N}(\alpha):\psi\to[0,1]$ represent membership functions for truth, indeterminacy, and falsity, correspondingly and exhibits the following relation:

$$0\le\lambda_{(neu)^N}(\alpha)+\beta_{(neu)^N}(\alpha)+\gamma_{(neu)^N}(\alpha)\le 3$$

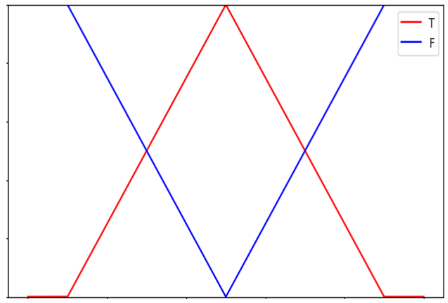


FIGURE 3. Triangular Intuitionistic Fuzzy Number

Definition 2.7. A triangular single valued neutrosophic $(\widetilde{tr_{SVN}})$ represented as $\widetilde{tr_{SVN}} = <((s,t,q);\sigma_{\widetilde{tr_{SVN}}},\varsigma_{\widetilde{tr_{SVN}}},\tau_{\widetilde{tr_{SVN}}})$ is represented in Figure 4, where $\sigma_{\widetilde{tr_{SVN}}},\varsigma_{\widetilde{tr_{SVN}}},\tau_{\widetilde{tr_{SVN}}} \in [0,1]$. Here the truth, indeterminacy, and falsity membership functions are defined as follows:

$$\sigma_{\widetilde{tr_{SVN}}} = \begin{cases} \frac{(\psi-s)\sigma_{\widetilde{tr_{SVN}}}}{t-s}, & \text{s} \le \psi \le \text{t}; \\ \frac{(q-\psi)\sigma_{\widetilde{tr_{SVN}}}}{q-t}, & \text{t} \le \psi \le \text{q}; \\ 0, & \text{Otherwise.} \end{cases} \quad \varsigma_{\widetilde{tr_{SVN}}} = \begin{cases} \frac{(t-\psi+\varsigma_{\widetilde{tr_{SVN}}}(\psi-s))}{t-s}, & \text{s} \le \psi \le \text{t}; \\ \frac{(\psi-t+\varsigma_{\widetilde{tr_{SVN}}}(q-\psi))}{q-t}, & \text{t} \le \psi \le \text{q}; \\ 0, & \text{Otherwise.} \end{cases}$$

$$\tau_{\widetilde{tr_{SVN}}} = \begin{cases} \frac{(t-\psi+\tau_{\widetilde{tr_{SVN}}}(\psi-s))}{t-s}, & \text{s} \le \psi \le \text{t}; \\ \frac{(\psi-t+\tau_{\widetilde{tr_{SVN}}}(q-\psi))}{q-t}, & \text{t} \le \psi \le \text{q}; \\ 0, & \text{Otherwise.} \end{cases}$$

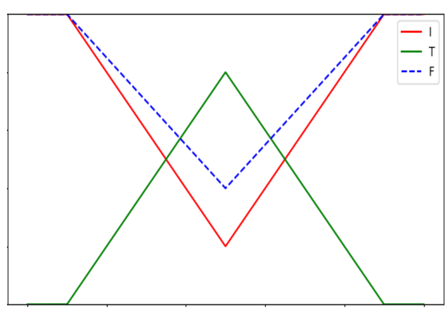


FIGURE 4. Triangular Single-Valued Neutrosophic

3. Impact of various techniques under uncertainty

Decisions in many areas have greatly benefited from the application of operational research methodologies. To solve such complex problems and apply more efficient statistical analysis methods, statistical modelling and optimization techniques come into the field to measure and control uncertainty, necessarily due to inherent unpredictability and variability in real-world conditions shed light on possible consequences and risks, enabling decision-makers to make choices that they choose very informedly. Organizations could make better selections and broaden stronger techniques after they incorporate uncertainty into their decision making. The following Table 3 provides a top-level view of several well-known overall performance appraisal techniques for dealing with uncertainty in numerous industries:

Table 3. Influencing the impact of uncertainty in various techniques

Main Contribution	**Environment**	**Author(s) Information and Year**
To resolve the shortest direction hassle via network problem considering the uncertainty and imprecision	Single valued Triangular Neutrosophic	Broumi et.al., (2019) [24]
To solve the transportation trouble and gain a most useful solution	Triangular Intuitionistic	Pathade et.al., (2019) [25]
A novel ranking feature and demonstration of the utility in the subject of integer programming	Triangular Neutrosophic	Das and Edalatpanah (2020) [26]
Implementing a direct model that facilitates the inclusion in linear programming to allow extra accurate consequences	Triangular Neutrosophic	Edalatpanah (2020) [27]
To endorse and investigate at the software of inventory backorder problem	Triangular Neutrosophic	Mullai and Surya (2020) [28]

Based at the studies above, those strategies have emerged as beneficial systems in the discipline of operations studies incorporating unique environments in their fields for acquiring the most efficient solution. Among the operations observer's strategies, the CPM and PERT have emerged as powerful gear for coping with uncertainty in project making plans and control.

4. Extended Fuzzy principle under CPM/PERT

Fuzzy theory is an extension of traditional fuzzy theory, whose objectives satisfy limitations, solving the robustness of fuzzy discrimination. As the extension under the concept of fuzzy gadgets by parameters and methods adding more accuracy and greater complexity. Fuzzy numbers can express uncertainty through their ability to describe the membership of a set. These membership functions can take many forms, including triangular, trapezoidal, or Gaussian, and can be used to generate imprecision and ambiguity that allows for a more accurate model, because it considers a feasible range of values within a triangular shape. This preferred modeling function is especially valuable in formulating and problem-solving situations where uncertainty plays a dominant role. This advice led to the use of multiple areas, where the addition of CPM and PERT made it difficult to control applications.

To effectively plan and handle challenges in the face of uncertainty, project managers may benefit of combining CPM and PERT with protracted fuzzy theories. It enables accounting for genetic ambiguity and variability in project data, leading to improved decision-making and more reliable project outcomes Furthermore many researchers such as Chakraborty et.al., (2018) [10] explore in-depth analysis on the categories of triangular neutrosophic numbers. Further, Mohamed et.al., (2017) [29] directly establish a connection with critical route and neutrosophic numbers by the use of triangles by their performance on the critical path problem as well as Mohamed et.al., (2017) [30] explore critical path problems in a neutrosophic context, and shed light on the use of neutrosophic numbers analysis in business processes and critical paths. On working with different categories, Vijaya et.al., (2022) 31 provide insights into the critical approach required in fuzzy project networks using neutrosophic fuzzy numbers, establishing a relationship between fuzzy project networks and the use of neutrosophic fuzzy numbers for project schedule analysis is summarized by the use of extended fuzzy theory and triangular fuzzy numbers that presents valuable extensions combining fuzzy logic with CPM/PERT technique that enables to handle the uncertainty in project management, and leads to better project planning, risk assessment, and overall project performance.

Conclusion

In task management, CPM and PERT are widely recognized as an effective tool in planning and scheduling complicated projects. Extending the application of these fuzzy concepts gives big improvements, especially in coping with the uncertainties and ambiguities having inherent information in large-scale projects. Fuzzy CPM/PERT adds fuzzy logic to traditional project management techniques for a more realistic and flexible way to estimate activity time and schedule. This integration accommodates unrealistic and variable real-world projects with fuzzy numbers, rather than crisp criteria. Mostly predictable resulting is more efficient and effective in project execution field, while working with uncertainty. The use of fuzzy CPM/PERT is especially beneficial in large projects, where it helps the project size, reducing the delivery time frame, and the margin of error to be minimal.

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