A Comprehensive Review on the Application of Fuzzy Logic in Risk Analysis

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ABSTRACT
Safety performance, together with productivity and quality, may be a primary objective for businesses looking to compete in the global scale in the innovative world of history. Every person has a right to safe, and that it is the duty of all sectors to work toward an accident-free workplace. Risk is defined as the probability that a potentially harmful event going to happen along with the intensity of any potential harm, damage, or loss. Major dangers and damages in particular have been managed through via means of statistical danger assessment techniques. a variety of techniques can be used to conduct risk assessments. Expert judgments are commonly employed to describe hazards since accurate data collected, which is typically needed for risk assessment, is frequently inaccessible in so many regions due to the lack of an accidents reporting system. Risks cannot, however, be compared because different evaluations by different specialists may produce different outcomes. Fuzzy logic analysis is one of the most crucial methods for reducing uncertainty and complexity in risk. This paper discusses fuzzy failure mode effect analysis (FFMEA), fuzzy failure mode effect analysis (FFTA), fuzzy Neural classifier (FBN), fuzzy failure mode effect assessment (FFMECA), fuzzy fault tree assessment (FETA), fuzzy failure mode effect assessment (FHAZOP), fuzzy key risks (FRM), fuzzy failure mode effect assessment (FLOPA) and additional hazy danger analytical methods like fuzzy Markov process and fuzzy Bow-Tie Assessment before discussing some of the uses of fuzzy set principle to risk analysis, explains the fundamentals of fuzzy principle..

Keywords
Network, Risk analysis, Bayesian network, Fuzzy logic, FTA, FMEA

1. INTRODUCTION
Many different sectors, including petrochemicals, aviation, autos, pharmaceuticals, and energy, apply fundamental safety frameworks. This category includes anything from car airbags to the propulsion systems used in orbital spaceflight, yet they all share the same risk of catastrophic failure for people and the environment. Safety basic frameworks are frequently unstable and insecure as a result. The ability to perform a planned capacity notwithstanding a blockage, which is often a security need, is referred to as unwavering quality. The ability to avert damage to the environment and humans is referred to as being in good health. The two qualities are crucial, and as frameworks become more complicated, their prediction through inquiry performs a bigger part in the best planning and improvement of the framework. However, different levels inquiries get harder.

Risk analysis comes in two flavors: Early in the project, possible accident scenarios are identified and rigorously examined to provide an accurate risk assessment using both qualitative and numerical methodologies. Examples of qualitative methods include PHA (preliminary hazard analysis), HAZOP, FMEA, and What-If Analysis. The mathematical technique improves risk decision-making by providing more detailed risk assessments for this unique case, even though it does not predict future accident occurrences. Examples of quantitative methodologies are the Layer of Safety Assessment, FTA, ETA, and Dow Ratio. A range of probabilistic risk assessment (PRA) techniques were utilised investigate the hard. The most used PRA technique for predicting device dependability and protection is FTA.

FTA is beneficial for pinpointing the origin of a disaster. The scenarios of the framework's component parts can also be used to determine the likelihood of the eventual occurrence. The most straightforward way to express a problem with immutable quality is to utilize the conventional Boolean symbols AND, OR, and NOT. Traditional FTA treats the likelihood that a structural (system) piece would fail as an appropriate attribute. However, it can be challenging to calculate the precise disappointment costs or probabilities of specific portions or unhappiness occurrences inside the qualitative FTA based on past occurrences or life experience for various frameworks. In structures with weak or insufficient competence for quantitative derivations, fuzzy set study is conducted under dynamic settings. It could be necessary to manage with stochastic estimations that are only estimated in the omission of complete information. It can be required to use the basic FTA to analyse the likelihood of structural collapse in certain scenarios due to the inaccuracy of the data and information in fundamental events. Fuzzy fault tree investigation is an alternate technique. That need precise and trustworthy information about the base events in order to analyse the viability of a model in FTA techniques. Businesses that lack pertinent or accurate information frequently experience problems. It is suggested that use FFTA to resolve this issue. Regular procedures demand caution and awareness in the event of large incidents, but by fusing fuzzy logic with FTA, the issue of insufficient data and knowledge can be resolved [1].

Two important factors or pieces of knowledge that have a significant impact on the risk associated with an event are the possibility that something will happen and the outcomes of winning the game. One of the easiest methods for recognizing and ranking threats is the risk matrix. These values are then including the identified risk to get an overall risk degree or ranking. Typically, the risk impact of likelihood and consequence is assessed. The risk assessment matrix has traditionally been viewed as a risk calculation tool. It was developed utilising precise data. It is challenging to make a precise estimate of potential expenses, including reputational harm, the negative consequences of bad press on future sales, and a number of workplace hazards fraud - related and continuity planning. In answer to this kind of issue, the conventional risk matrix was enhanced to give a risk rating database, resulted in a fuzz risk matrix. The capacity to add linguistic expressions and traits that are frequently connected to imprecise or hazy judgments into the process is one advantage of a fuzzy risk matrix [2].

It appears that Mode of failure, impact, and Comprehensive Evaluation is a method that is used covertly to examine the outcomes and implications of recognized probable failure modes at higher levels of the system hierarchy. By creating a risk paramount, FMEA typically performs an evaluation of importance or likely threats (RPN). Despite what has been said, the RPN has been the subject of significant investigation for a number of factors. The mixture of 1000 RPNs contains some things that aren't original and some items that are regularly repeated. These RPNs appear to be broadly scattered near the very same bottom of the scale on a histogram. Using this method, it is difficult to determine if RPNs 1 and 2 have the same change between 900 and 1000 or not. Fuzzy logic can help conventional RPN-based FMEA overcome some of its drawbacks. -level sets and The RPN estimate can be the same for different risk factor variations, yet one's concealed risk implications may be wholly unanticipated. Simply on RPN, small modifications in a grade might have vastly different outcomes. The perceived significance of the three risk variables, which may or may not be suitable in practice, is not taken into account by RPN. The fuzzified growth approach were used to register the FRPN. To find FRPN-level arrangements, the conventional transformation search computation was applied. The fuzzy approach of detecting mode of failure by attaching an ambiguous assurance to unique spoken phrases may be a good indication of evaluated data if given the unclear, subjective facts, and unknowns [3].

A sophisticated analytical approach for assessing how well processes is safeguarded is called LOPA. It takes a small amount of time and effort of other methods to get quantified risk findings. However, due to the limited sample size and very short operating history, data from many entrepreneurs is sometimes scarce and statistically erroneous. This restriction can be overcome by using the Nave Bayes LOPA method. Using conjugate gamma distribution, it can continue to update basic information with tree data Steenberge. The Safety Integrity Level (SIL) may be measured, the unsteady approach can be utilised anticipate the frequency of beginning events and tackle the issue of large industry collapse. Fuzzy logic-based systems are trustworthy and can be modified to produce the most precise and consistent results Mannan.

2. THE BASIC OF FUZZY LOGIC

In 1965, Lotfi developed the uncertain inference system device as a method for dealing with uncertainty in mathematics. The fundamental idea of word computation is given a soft computing connection. It provides a method for dealing with mistakes and details of various granularities. Fuzzy logic is an induction concept that enables for suitable human thinking abilities and is utilised to express many linguistic expressions, such as "many," "low," "centre," "frequently," and "few." Contrarily, the basic bit set theory focuses mostly on sharp occurrences, or events that either happen or do not happen. The fuzzy inference system tool was created in 1965 by Lotfi as a way to cope with mathematical uncertainty. A soft computing connection is made to the core concept of word computation. It offers a technique for handling errors and details of different granularities. Zadeh (1965). In figure 1 shows that the fuzzy logic method that accommodates ambiguous expressions and inaccurate data such as small, medium, and high and offers judgments has been illustrated.

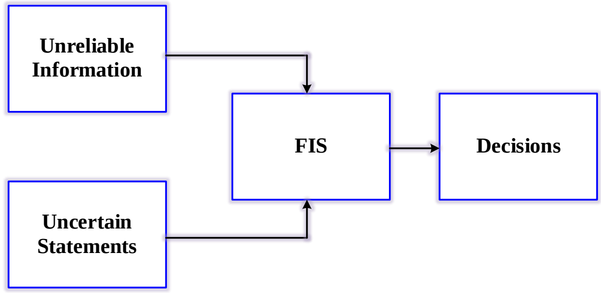

Fig 1: A fuzzy logic method that accommodates ambiguous expressions and inaccurate data such as small, medium, and high and offers judgments

2.1 Fuzzy Sets

In order to identify not whether an event will occur, probability the application of theory determine the likelihood of a given presence. The foundation of fuzzy logic theory and mentation or cognitive activity is the concept of relative grade membership. The advantage of fuzzy sets is that they can show ambiguous or disputed information, which happens much too frequently in reality.

The scaling factor of the crisp set, which distinguishes between specific people and out groups in the pertinent sharp set, provides a value of 1 or 0 to each member of the standardised set. The value-containing components of the universal set are added up to reveal their degree of set membership within a predetermined range. Additionally, a membership function identifies the gathering, which would be a loosely defined set, by accumulating significant values as it denotes higher degrees of apparent brilliance. In conclusion, a convoluted is a group of elements with varying degrees of aesthetic appeal. Individuals possessing a numerical set, in contrast to this assertion, would not have been participants if their involvement in that set was whole or perfect (i.e. They are assigned a value of 1 for membership). due to their engagement does not seem to be fully complete, individuals in a fuzzy set of rules can really be inhabitants of all other fuzzy sets within the identical world. A setting indicator with a vowel sound under the strokes signifies a fuzzy set.

The true value of the fuzzy set falls among 0 and 1. The mapping would be complete if were a component of the cosmos, say x, and it belonged to the fuzzy set A, which is [0,1] Figure 2 Sivanandam et al shows how the participation mapping was represented.

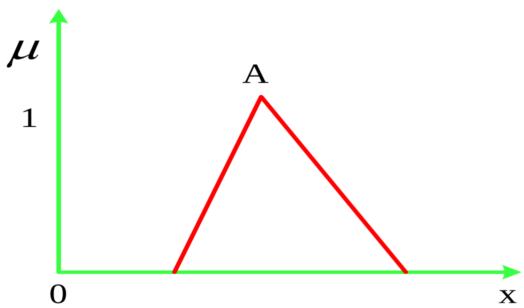

Fig 2: Membership formula for the A fuzzy set

2.2 Linguistic Variables and Membership

Functions

A collection of components with varied degrees of visual appeal is referred to be a complicated. This allegation immediately contradicts the notion that if a person's participation in a numerical set was complete or complete, they would not have been a member (i.e., They are assigned a value of 1 for membership.). Members of a fuzzy rules can truly live in all other fuzzy sets fuzzy in the similar world, regardless of that their involvement does not appear to be entirely complete. A fuzzy set is indicated by a setting icon with a vowel sound beneath strike. where x is the foundation variable as well as risk capacity is the generic numeric value. A fuzzy set is a group of items with varying degrees of participation [4]. The next step was to develop a participation system (MF), A(x), which interacts a real number in the range [0, 1] with every point in X. The value of A(x) at x represents the " membership level " (GOM) of x in A. Consequently, a fuzzy set is referred to as a locating.

$$\mu : X \rightarrow [0,1]$$

Fig. 3 illustrates an example where each item is given a membership grade scale from 0 to one using a membership function that distinguishes it (MF), in this case high(x). Indicating a high- danger ability collection of clients, those with risk tolerances of 50% or less received a score of 0, while those with risk capacity of 80% or more received a score of 1. There is ambiguity in the classification given to the client's risk attitude for each of those risk capacity (50 percent, 80 percent). If the MF resembles Figure 3's shape, it is said to be S-shaped. Figure 4 shows four other frequently used MF types: modified bell, triangular, trapezoidal, and Gaussian. Many of the fundamental characteristics that apply to conventional sets for fuzzy sets are expanded. As a result, the most compact fuzzy set with both A and B is the unity of the twin fuzzifications, A and B.

$$\mu_{A \cup B}(X) = \max[\mu_A(X), \mu_B(X)], x \in X$$

and each of them includes the largest amount of uncertainty, which is typically characterised as [5].

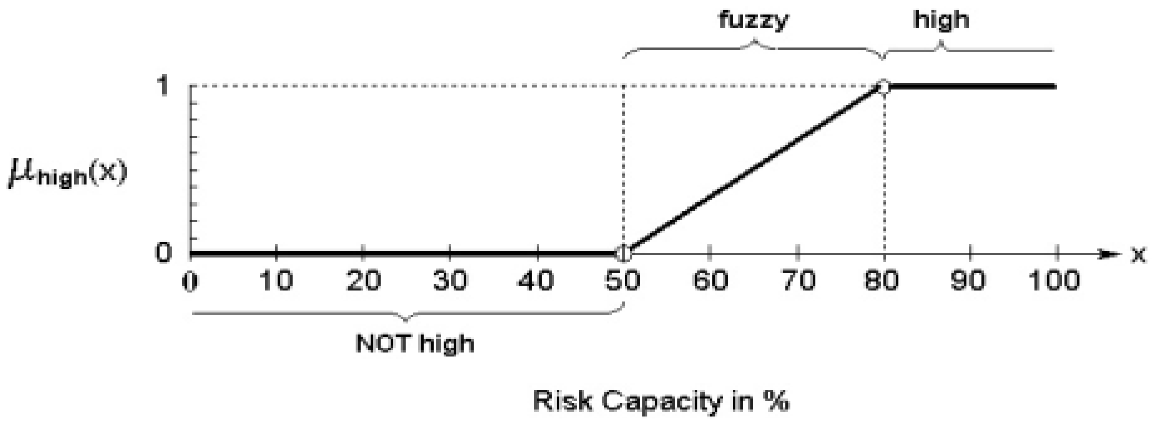

Fig 3: (Fuzzy) a group of clients with a high-risk tolerance

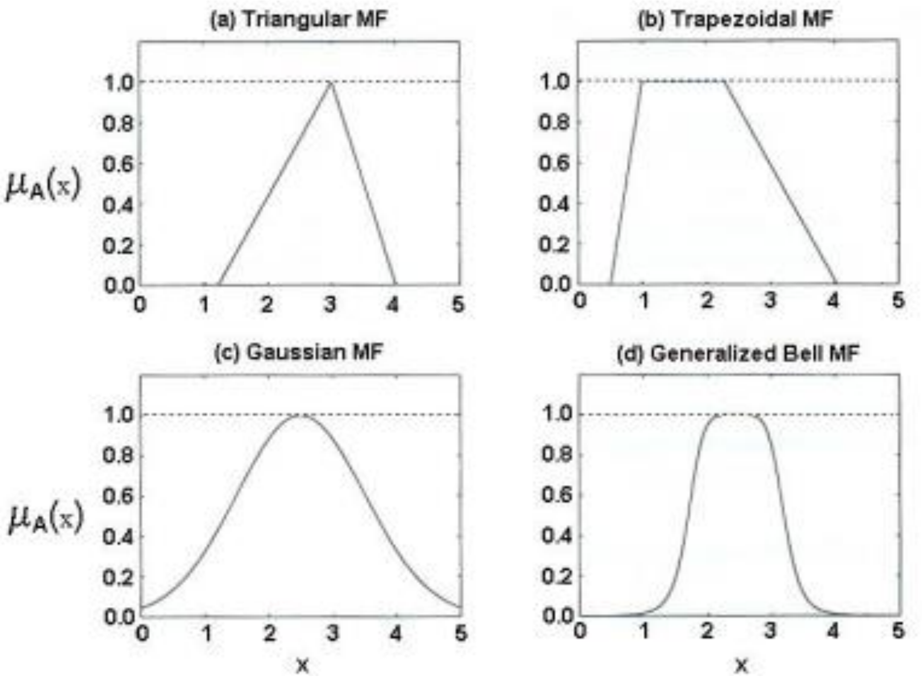

Fig 4: Examples of Classes of MFs

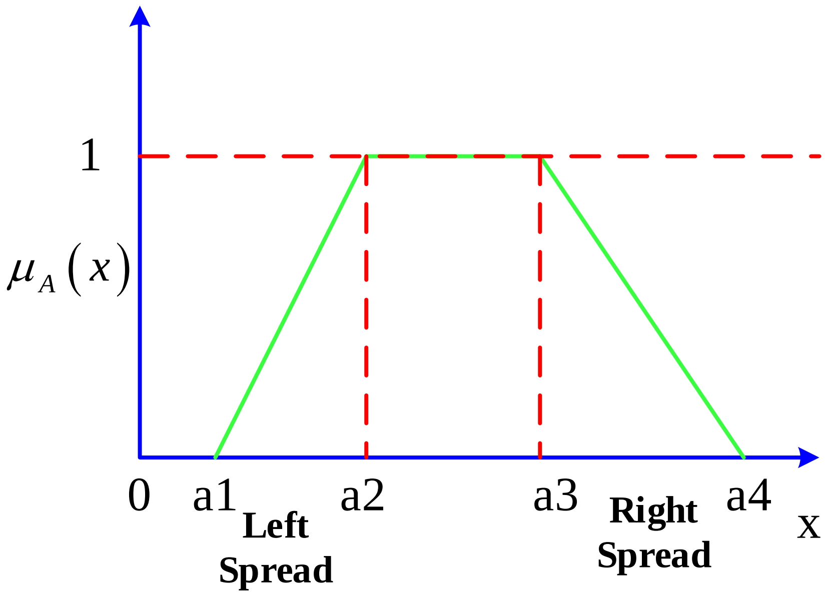

Fig 5: Fuzzy Flat Number

2.3 Fuzzy Numbers

A convex fuzzy number is an integer that is a member of

$$\mu_A(\lambda x_1 + (1-\lambda)x_2) \geq \min(\mu_A(X_1), \mu_A(x_2)), \lambda \in [0,1]$$

the real line's fuzzy set A.

A has been normalised, so

$$\exists x_0 \in R \,|\, \mu_A(x_0) = 1$$

μA is an ongoing piece by piece. For instance, the expressions "approximately 6%" and "very high" are unclear quantities. According to the circumstances, any of the curricular of MF represented in Figure 4 can be utilised as a fuzzy set, as demonstrated by the general characteristics of Figure 5. Zadeh (1975)- Dubois et al (1980). The shape of this puzzling number is neither "flat" nor "trapezoid," and its MF is usually written. The following: (a1, a2, a3, a4) If both a1 and a4 are positive, then the fuzzy number is positive. both the left and right spread are the length of the periods [a1, a2] and [a3, a4], accordingly, and they will be refer to as and, correspondingly. When a2 = a3, a triangle fuzzy number (TFN) is produced, and its MF is represented by (a, β), where a stands for its mode, which is termed to as its centre value. The TFN is recognized as a symmetric TFN and is denoted as (a,β) when two spreads are equal.

2.4 Fuzzy Linear Programming

The majority of insurance fuzzy inference system research on decision-making employs [6]. The key idea is that G & C merge to start constructing an alternative, D, which, given a non-fuzzy group of subjects, X, a fuzzy aim, G, or a fuzz limit, C, is a fuzzy set that results starting from the G/C integration. Provided that the objectives and limitations are inserted into the D equation in the same manner, Figure 6 illustrates a straightforward depiction showing the connection between G, C, and D. The selection should be made based on the number of alternatives and the fuzzy sets of the target or limitation MF intersections in the xL to xH area. The issue can be readily resolved if the option in the decision set with the biggest participation standing is the best alternative.

$$X^* = \arg[\max \min\{\mu_G(X), \mu_C(X)\}]$$

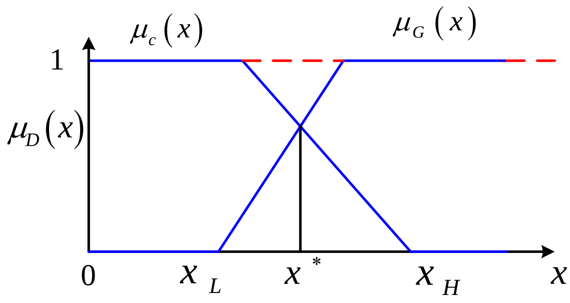

Fig 6: Making Decisions

In this study, that investigate the efficacy of fuzzy linear programming (LP) in judgement. Fuzzy LP may include recognising an x in a manner that is similar to that of its crisp equivalent.

$$C = \sum_{ij} c_{ij} X_{ij} \overset{\approx}{\leq} C_0$$

$$Z_i = \sum_{ij} a_{ij} X_{ij} \overset{\approx}{\leq} b_i$$

$$X_{ij} \leq 0$$

Where "~" Over the coefficients denote the acceptable and fuzzy forms of a symbol, respectively. The objective function's ambition level is C0, although aij, bi, and cij are not always exact integers. This fuzzy LP issue can be handled by rewriting it as a hard LP issue [7]. The essential components of one confront are shown in Figure 7.

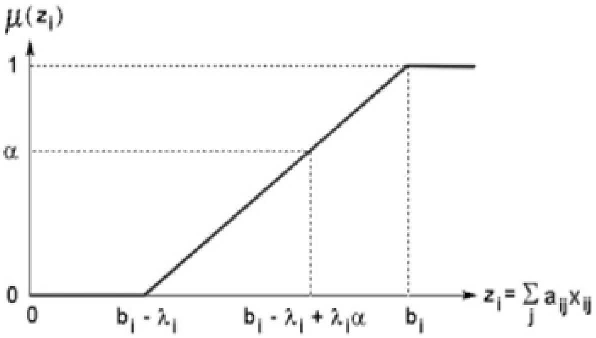

Fig 7: Crisp Equivalence Restriction

Zi has an uncertain definition and a zero participation is a feature of zi ≤bi - λi, one for zi ≥bi, besides linearly rising in the gap, as seen As a tolerance range λ zimmermann relates to it. As can be seen in the diagram, a similar limitation exists. zi ≥bi - λi + λi α when using a α–cut to determine an acceptable minimum standard of fulfilment, i.e. μ(zi) ≥ α is an accepted constraint. The same goes for CC0 + -. Due to these constraints, the analogous crisp programming issue is reduced to a maximisation problem:

$$Maximize : \alpha$$

Subject to:

$$Zi - \lambda i\alpha \geq bi - \lambda i :$$
$$C + \lambda\alpha \geq C_0 + \lambda :$$
$$0 \leq \alpha \leq 1.$$

2.5 Fuzzy Inference System

Using the fuzzification approach is a common way to apply FL (FIS). FISs are also known as fuzzy methods of control, fuzzy modelling, fuzzy memory (FAM), fuzzy inference structures, and fuzzy control when employed as controllers [7]. Figure 8 illustrates the skills and processing stage that make up the FIS. The MFs and fuzzification for the application are stored in the knowledge base. During the processing stage, the software is fed with numerical crisp variables. Fuzzification is the process of converting knowledge into conditions that can be utilized to draw conclusions. This hazy insight is transformed into a hazy output by the principles of the inference engine. Such verbal discoveries are translated into numerical numbers through a fuzzified stage, which are then employed as the output of the system. For the purpose of integrating or combining input data and weights, the "t-norms" (rectangle-shaped) and "t-co recommendations" are strategies used by FISs (their counterpart). the minimum and maximum operators, respectively, are the fundamental building blocks of a t-norm and a t-co-norm. A claim that a number of sorts of work can be used as t-norms. Figure 9 displays the Mamdani FIS, which regularly appears in health policy studies [8].

With j=1, 2, and three sets of classifiers (Aj, Bj, and Cj), Two precise inputs are present (x0 and y0). The fuzzy intersection denoted by the conjunction "and" in the rule Aj and Bj Cj is each set of membership functions. The least the first two columns of the fuzzy inputs determines the firing levels and how they affect the implication findings (as evidenced by the third column's darker portions). Column three's third row's fuzzy set in that column serves as an illustration of the larger conclusion by integrating the dark portions of the preceding two rows. A general conclusion is defuzzed to a number that, in certain aspects, most closely resembles it. In insurance articles, the centre of gravity technique is frequently used to define the output's numerical value as the union's abscissa. In reality, Wj is the membership function's relative value at xj ,and this is determined as follows: wj = (xj) / j xj.

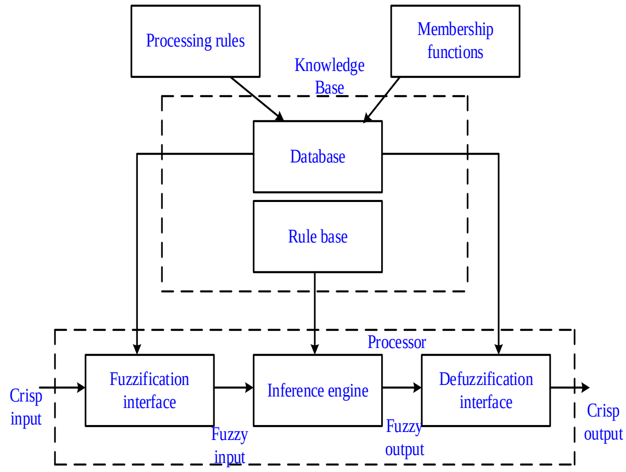

Fig 8: Fuzzy Inference System

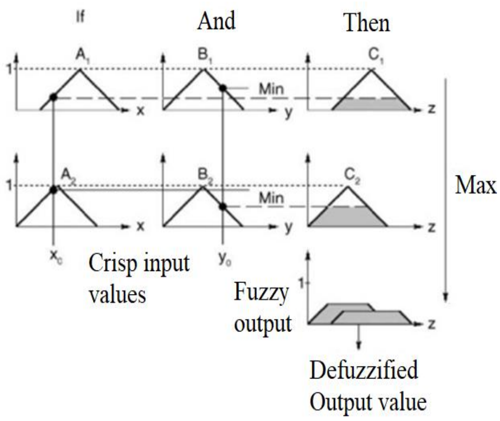

Fig 9: Fuzzy Inference System

3. FUZZY FAULT TREE

For the purpose of analysing system crash logic and determining overall dependability, using top-down, logical reverse reasoning, fault tree analysis is a method. FTA is frequently utilized. It was developed in 1962 at H.A. Watson. Boolean algebra and logic diagrams are both employed to pinpoint the precise origin of the big incident. The potential that a top incident will occur is determined by assigning likelihood of occurrence values to the lower-level events in the tree.in industry for a number of purposes, such as identifying the root cause of a failure, coordinating and managing a complicated system's safety performance, assessing the effects of human error, and minimizing and maximising resource usage. On either hand, standard FTA has many disadvantages, including handling uncertainty, utilising linguistic considerations, and even embedding human errors in the flawed logic model. Fuzzy has therefore been proposed as a method to get around the limitations of traditional FTA. Similarity, uncertainty, and desire are all basic ideas that fuzzy logic may effectively represent.

A [9] created a "gate," sometimes known as a simple rational gates, from fuzzy theory [10]. Dokas integrated a fuzzy decision First time using an expert system to analyse a tree, producing a much-improved basic event tree that could predict accidents and detrimental variables in advance as well as evaluate the anticipated implications of a mistake. Because of this, risk management benefits greatly from this. As a result of the numerous benefits mentioned above, FTA has been widely used in many industries, encompassing human services, nuclear power, chemical industries, aviation, and transportation. In order to analyse the petrochemical processing business, Lavasani constructed a fault tree [11]. Zadeh created fuzzy set theory to deal with inexact and fuzzy situations, and it has made tremendous progress [12]. Tanaka proposed an FTA analytical method, where the probabilities of top and bottom incidences on fault trees are again substituted by fuzzy probabilities from exact probabilities [13], in order to incorporate fault tree theory x with fuzzy mathematics. More information on this was provided [14-17]. used fuzzy principle to investigate spillages via the PA natural gas and oil wells being drilled business. They made use of a hazy FTA (FFTA). In the chlor-alkali business, Renjith was utilising an FTA to calculate the likelihood that chlorine had been released from a facility for storing and filling [18].

Using probabilistic research methodologies, the likelihood recognises the fundamental events in regular FTA (crisp numbers). It is assumed that precise event probability and pertinent failure information are presented. In any event, many state-of-the-art systems appear to be quite robust, making it more challenging to gather sufficient statistical data to determine precise rate of failure and chances. Furthermore, human error makes it difficult to handle the lack of precision associated with an ideal pattern using traditional stochastic reliability hypothesis procedures. Due to significant problems with both the hypothesis and the standard probability definition of durability, academics have already begun looking for alternate techniques to supplement it. The solution to this issue can be found in fuzzy set principle. FTA analysis was created. In order to deal with these difficulties. For a number of fundamental occurrences, valid failure statistics are not currently available in industrial practise. Calculating fundamental incident details should be done using expert annotation and decision. To improve the reliability of basic event failed data assessments, it is possible to apply organised specialised elicitation techniques. To determine the probabilities of fundamental events, fuzzy logic and expert elicitation are also used. The FTA method and fuzzy set theory are used to create a structure that is suitable for examining expert opinions that communicate qualitative recommendations. With the uncertainty surrounding the probabilities of basic occurrences taken into account, using this approach, risk could be evaluated and choices could be made. [19].

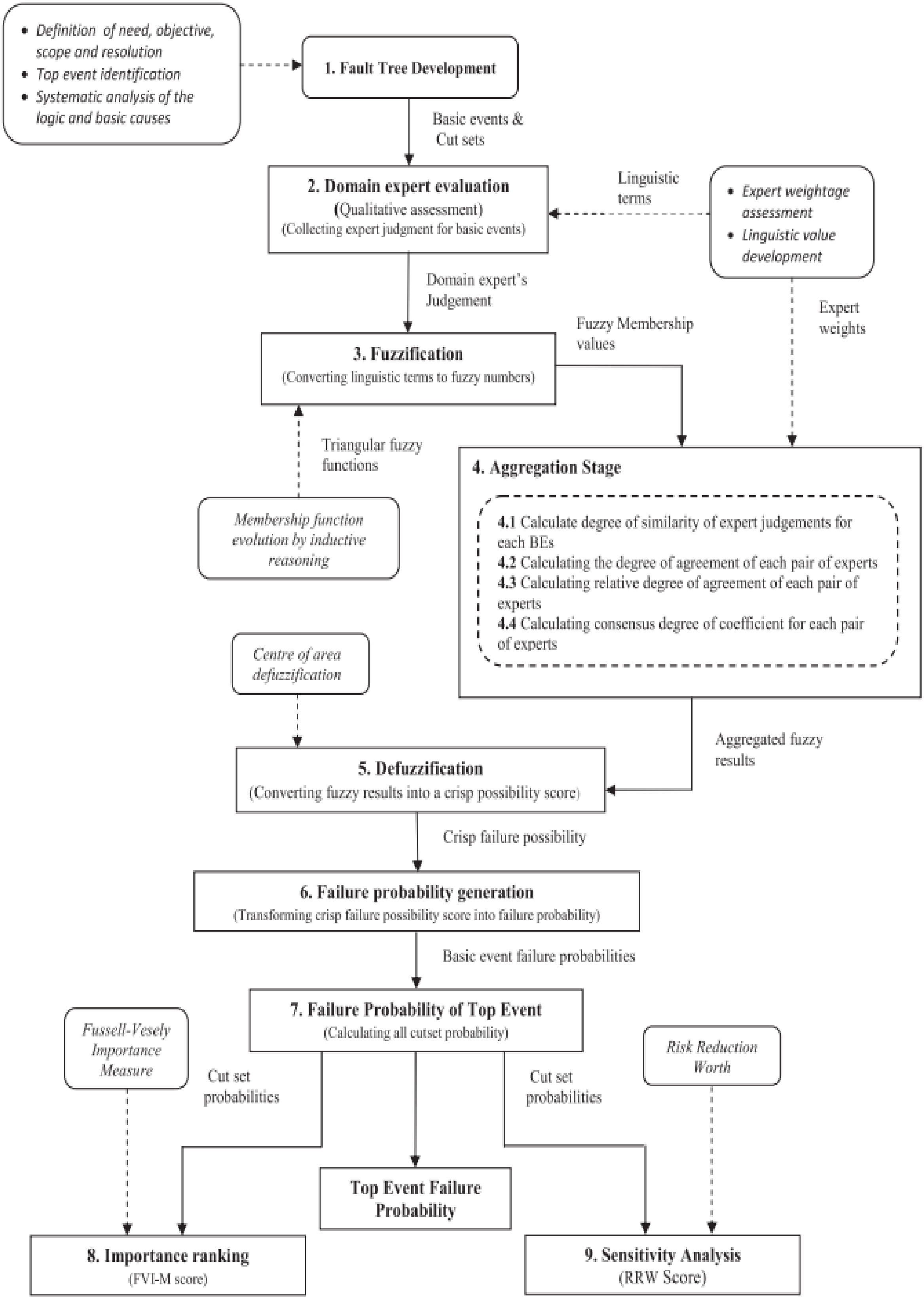

Fig 10: Framework for FTA analysis

3.1 Methods for Fuzzy FTA

Step 1: To build a fault tree, standard events are systematically examined.

Step 2: Expert evaluation of fundamental linguistic occurrences by subject-matter specialists

Step 3: Conversion of specialist extraction to fuzzy numbers

Step 4: expert elicitation and combination

Step 5: converting the result's ambiguity into a clear potential score

Step 6: Create a straightforward event failure probability using the possibility score.

Step 7: Estimate the likelihood that top events or cut sets will not succeed.

Step 8: By ranking them, may establish how important cut sets are.

Step 9: Perform a sensitivity assessment to find the sensitivity of the ultimate activity.

In [20] released a significant article on the based on the fuzzy set principles to FTA has been figure 10. The basic occurrences of a fault tree's failure possibilities were expressed in this study as fuzzy integers, and the likelihood that each event would occur in the fault tree's fuzz form was calculated using these numbers. In [21] proposed a way for inserting crucial metrics into the fuzz FTA as a follow-up to this work. Based on more study was conducted in [22, 23]. That can read more about fuzzy FTA research in [24-27]. As observed in [28-33], extensions of dynamic fault trees use fuzzy set theory.

3.2 Operator For Fuzzy Logic

Considering that (a1, b1, c1) and (a2, b2, c2) may be utilised to construct the triangular fuzzy numbers PI and P2, the algebraic processes for the fuzzy numbers P1 and P2 are as follows:

AND fuzzy operator of gates

PAND = G Pi, where Pi(i = 1, 2,..., n) indicates the exact likelihood of the event I is Pi, is the "AND gate" operator in classical FTA. Here is the fuzzy operator:

$$P_{AND} = \prod_{i-1}^{n} p_i = \left[\prod_{i=1}^{n} a_i , \prod_{i=1}^{n} b_i , i = \prod_{i=1}^{n} c_i , \right]$$

The algebraic formula is PAND = min(P1, P2,……. Pn) if the events are inter - dependent.

OR a fuzzy gate controller

The "OR gate" fuzzy operator is expressed by: POR = (1-Pi) in conventional FTA, where Pi is the precise likelihood that occurrence, will happen with probability pi.

$$p_{OR} = 1 - \prod_{i-1}^{n} (1 - P_i)$$

$$1 = \left[\prod_{i=1}^{n} (1 - a_i), \prod_{i=1}^{n} (1 - b_i), \prod_{i=1}^{n} (1 - c_i , \right]$$

If the occurrences are related, the algorithm is POR = max(P1, P2,.... Pn) [34]. The fuzzy average and fuzzy sum techniques were developed for FFTA by [35-38]. A mean procedure that includes the AND and OR procedures is known as a fuzzy mean. The fuzzy sum process generates the influence of input values as they add together. In [39] says that in arrange to determine the possibility of system malfunction, fuzzy AND and OR operators are utilised. However, the decision to acquire the positive and negative system accident possibilities is made for each value of m from (m,). They are enlarged to fuzzy FTA with main and minor TFNs in order to improve results.Even though AND and OR gates are frequently used in FTA , it can be difficult to describe the structure of the system using these two gates. This is due to the fact that early in the design process, in many situations, clear understanding of the system crash mechanism is not accessible. In [40] used fuzzy sets principles to create the fuzzy system structure since it is frequently impossible to establish precise links between components in sophisticated and complex networks. They presumptively believed that the gates were portrayed as a blurry relation. Several studies used a special gate built on the T-S fuzzy models to address these challenges.

Fuzzy FTA has been used in many different contexts. This methodology was utilised by [42] to predict the probability of chlorine leakage out of capacity and refuelling infrastructure in the chlor-alkali sector. In [43] used it to reduce danger at Refueling stations for LPG. Daqing Wang (2013) was used to quantify the likelihood of an explosion and fire in an oil storage facility. Nuclear power stations are subjected to a probabilistic safety assessment by [44,45]. This method has been used in many different sectors for both defect detection and risk assessment.

4. FUZZY FMEA & FUZZY FMECA

4.1 Fuzzy FMEA

With a focus on eliminating defects, safety, and customer engagement, it is a method for figuring out and removing product and process faults before they arise. The first official FMEAs, which were centered on safety issues, were conducted by the aircraft industry in the middle of the 1960s. It looks at the many equipment malfunctions that can happen as well as how these malfunctions affect the process. Every inability is handled as though it were a separate event. The intensity, occurrence, and detection of an inability all have an impact on the relative risk of that failure and its consequences.

4.1.1 Risk Priority Number (RPN)

The following criteria are used to determine it: It is a quantitative and relative estimation of the overall risk connected to a particular failure mechanism.

RPN=OxSxD (1)

D continues to stand for detecting, while S represents for intensity, which has to do with the importance of the failure, should it occur. O stands for occurrence, which denotes the likelihood or regularity of a serious error. Using data and enough information or products, every potential method and effect of failure is assessed on a scale of 1 to 10, high and low, and this same likelihood of failure has been identified long before the effect's influence is realised. For each likely failure cause and impact, RPN is calculated. It's a scale that determines the importance of remedial action to avoid failure or reduce the risk that it will occur. When the intensity rating is high, special attention must be paid regardless of RPN after dealing with the failure strategies with the highest RPNs (9 or 10). In classical FMEA, the RPN tier uses a system to rank failures, establish the highest priority actions, and assess the risk threshold of failures. Despite being simple, this tactic has a few shortcomings. The same conventional FMEA has in fact received criticism for a number of flaws, including,

(a) When RPN components are given equal weight, oversimplification results [58It disregards O, S, and D's respective importance. These three elements are seen as being equally significant. It might not be accurate when evaluating a real implementation of an FMEA technique (Pillay, and Wang 2003).

(b) The RPN elements include a large number of erroneous numbers. The method used to rank risks in conventional FMEAs is questioned. Prioritizing risk is achieved by devoting some of the few resources to some of the key risk components.

Even though the RPN values produced by various O, S, and D combinations may be identical, the hard prioritization may alter significantly. Consider the next two occurrences, which have O, S, & D numbers of 3, 6, 2 or 3, 2, 6 consequently. The risk implications of the two scenarios could differ, each has an accordingly RPN of 12 (RPN1 = 3 6 2 = 36 and RPN2 = 3 2 6 = 36), notwithstanding this Occasionally, this could result in a loss of time and resources as well as an incident that is metres tall [46].

(c) The RPN scale has a few statistical features that seem counterintuitive. The three criteria that make up the traditional RPN approach are all related to safety and do not address indirect component links. The validity of the RPN computations is the most significant issue in FMEA despite its widespread use [47-50]. The RPN, also known as the RP Fuzzy Number, is determined using a fuzzy FMEA. The RPFN will be determined utilising equation (2).

RP Fuzzy Number ij= $O_{ij} \otimes S_{ij} \otimes D_{ij}$ (2)

The fuzzy numbers Oij, Sij, and Dij are trapezoidal, according to formula 2, represent evaluations of incidence rate, severity, or detection given dimension I with failure mode j. It is possible to analyse the probability, impact, or detection factor using language. Tables 1 and 2 present, respectively, the linguistic word and fuzzy number used to assess probability, impact, and detection. That can also utilise the linguistic expressions included in Table 2 to determine the relevance of the L, I, and D elements. The following are the steps for performing a fuzzy FMEA analysis:

Table 1. Impact, likelihood and detection fuzzy number determination

No	Impact	Likelihood	Detection	Fuzzy number		
1	Insignificant	Rare	Almost Certain	1	1	2
2	Minor	Unlikely	Moderate	1	2	3
3	Moderate	Possible	High	2	3	4
4	Major	Likely	Low	3	4	5
5	Catastrophic	Almost Certain	Almost Uncertain	4	5	5

Table 2. Imprecise number determination in linguistics

Linguistic Term				
1	Very Low(VL)	0	0	0.25
2	Low(L)	0	0.25	0.5
3	Medium(M)	0.25	0.5	0.75
4	High(H)	0.5	0.75	1
5	Very High(VH)	0.75	1	1

Obtain the fuzzy number for L, I, and D using Tables 1 and 2 b. Equations (2), (3), and (4) should be used to get the sum of the fuzzy ratings for the parameters L, I, and D. (4).

$$R_i^L = \frac{1}{n}\sum_{j=1}^{m} h_j R_j^L = \left(\sum_{j=1} h_j R_j^L L, \sum_{j=1} h_j R_j^L M, \sum_{j=1} h_j R_j^L H\right) \quad (3)$$

$$R_i^I = \frac{1}{n}\sum_{j=1}^{m} h_j R_j^I = \left(\sum_{j=1} h_j R_j^I L, \sum_{j=1} h_j R_j^I M, \sum_{j=1} h_j R_j^I H\right) \quad (4)$$

$$R_i^D = \frac{1}{n}\sum_{j=1}^{m} h_j R_j^D = \left(\sum_{j=1} h_j R_j^D L, \sum_{j=1} h_j R_j^D M, \sum_{j=1} h_j R_j^D H\right) \quad (5)$$

This fuzzy technique (ii) can be used for systems with inadequate or erroneous safety data and integrates skills and knowledge for use in an FMEA study. It is a great situation when this same traditional RPN magnitude is transformed into a changing linguistic using the full set as input by such a specialist, since it (ii) does not require correctness but also enables users without linguistic expertise to utilise the system. that allowed to simply utilise the FIS. A fuzzy FMEA uses fuzzy if-then rules and competent assessments to prioritise failure modes based on risk. The objective is to rank o, s, and d using fluffy values (like trapezoidal fuzzy numbers) as opposed to clear integers, and to reflect o, s, and d as language aspects. For the three potential confounders O, S, and D, Participation performs must first be defined once again. once the classifications have been made, linguistic variables can be used to represent each risk factor. The three risk factors' expert judgement can then be compiled in the form of linguistic expressions. These language ideas have been combined with fuzzy rule bases to begin coming up with a linguistic term for the RPN. Creating if-then rules that transform expert failure mode assessments into fuzzier figures is the next stage. Because the fuzzy rule base might have hundreds of rules, making the fuzzy FMEA process difficult, techniques to lessen the number of rules that are in place developed. In [51], 125 fuzzy if-then rules were initially produced before being combined and whittled down to 25 rules. Examples include the reduction of 125 fuzzy if-then rules by the authors of [52,53] to 6, 14, and 16 rules, respectively. The method suggested in [54] uses 27 fuzzy if-then rules.

4.2 Fuzzy FMECA

The US military developed FMECA, which is considered one of the first systematic failed analysis techniques. Early on in the development of a system or product, it is frequently used. To make sure that practically all potential failure modes have been taken into account and that appropriate steps have been taken to prevent them, it is frequently done during the conceptual or early design phases of a system. However, this method can make it challenging to pinpoint accident sequences and connections between human activity and technology [55].

Potential equipment failure and accident situations can be fully described using fuzzy in failure modes, repercussions, and The FMECA approach focuses on the criticality of the individual systems and associated failure mechanisms. As a result, each error is only considered once, and the effects and controls are shown as a whole. The likelihood that a failure will be discovered through inspection or design controls is defined by a RPN, which takes into account the failure rate, the gravity of the repercussions, and the detection. can be used to determine the significance of each prospective failure analysis. This approach could be used to identify probable failure causes and their repercussions while also solving problems in an efficient manner. Moreover, it has the capacity to foster trust concurrently. It facilitates the examiner's basic criticality evaluation of linguistic concepts and aids in the identifying of dangers related to failure. In the review and organising process, ambiguity, personal factors, and data made up of quantitative data could all be used, but with caution. The severity (S), occurrence (O), or non-detection (D) structure of the combination of attributes were more flexible. The purpose of this work is to apply fuzzy reasoning to FMECA. In conventional hard assessment, quantity and intensity are conveyed as discrete values, but due to uncertainty, these figures lack precision. Renjith VR [56] presented a fuzzy FMECA technique in which number and intensity are conveyed as non-crisp numbers. When there is uncertainty in the parameters, fuzzy can be used to estimate risk. A fuzzy risk assessment matrix is produced to use a fuzzy frequency as well as a fuzzy severity. When it came to occurrence (o), severity(s), and non-detection (D), a fuzzy linguistic factor is used to connect these variables, and an if then rule is used to get fuzzy RPN. The issue of prioritising an RPN in a complex system is addressed.

5. FUZZY HAZOP

In the 1960s, research on operability and hazards were produced by Imperial Chemical Industries (ICI) in England. It was recognised for brand-new, large-scale, unique, single-unit, complex continuous processes. The capability of training programmes and rising regulatory requirements in the 1980s led to a rise in methodology's adoption. An extra impetus came from a string of significant catastrophes, including the 1974 disasters at Flixborough, Three Mile Island, Bhopal, Mexico City, and Chernobyl. Accident causes were shown to be predictable, but a more effective approach of locating and handling issues was needed. HAZOP proposed a method that was organized and creative for seeing dangers before they materialized. The most successful and efficient system security evaluation approach for locating potential threats in chemical facilities is the HAZOP technique [57]. The HAZOP's starting point is the unit's design purpose. The causes and implications of parameter fluctuations while the device was in operation, as well as potential production and controlling process stage parameter deviations, were also examined. Then, in addition to being obvious what the main risks or dangers of such a device or system were, it is also required to limit the impacts of change. However, HAZOP currently has a few issues: To begin with, it would be unable to evaluate the relevant significance of the components needed for the device to operate normally. The suggested therapies are not entirely feasible because HAZOP trials normally require a significant number of participants, material affluence, and economic competence. Based on the significance of the measures, the most efficient risk reduction approach must be designed given the limited resources. Despite semi-quantitative assessments of process sector safety utilising the HAZOP evaluation and sequential batch approach, as well as the LOPA and analytic hierarchy process, having been completed the basic safety of a process in the work process is still unclear. Fuzzy Integration Evaluation was developed based on HAZOP analysis to successfully address the aforementioned difficulties [58]. The synthetic furnace system's byproduct simmers during the technological preparation of high concentration in a corporation.

A four-step method has been presented by Jose Luis Fuentes-Bargues.

▪ Step 1 thoroughly investigates the industrial process, including the used manufacturing system, tools, machines, and goods.
▪ step 2 involves performing a HAZOP analysis to identify risks.
▪ Step 3 entails doing risk assessment (of the hazards identified in step 2) using linguistic and fuzzy numeric components.

▪ Step 4 entails evaluating risk using the levels that have already been set.

For step 3 Steps 1 and 2 must identify risk factor functional and linguistic scales, and steps 3 and 4 must create the threat assessment scale.

5.1 Risk Factor Function Definition

Risk likelihood, risk impact, and risk factor are all byproducts of one another (RP). The adverse event's or threat's impact on the system's environmental issues, safety, and other goals is known as the risk effect [59]. This link is shown by the formula below:

RF=RP.RI

5.2 The fuzzy numbers associated with the linguistics scales are also defined.

Members of a risk monitoring committee are limited to educated guesses when they are given inaccurate information regarding the project's risk. Risk monitoring groups occasionally convey their opinions verbally rather than statistically.

Risk Probability (RP) is rated on a five-point scale: critical (C), serious (S), moderate (Mo), minor (Mi), and negligible (Neg). The Risk Impact (RI) is rated on a three-point scale: high (H), medium (M), and low probability (L).

5.3 The parameters of RP and RI are Evaluated

5.3.1 Individual discretion

Using the provided linguistic phrases, each participant of a threat assessment team assesses the RP or RI of each identified danger. The fuzzy integers RPi m and RI m, where i is just t, are created from these language markers. The confusing numbers RPi m & RIi m are created from these linguistic indicators, where RI simply stand for the total number of risks identified and m for the total participants in the risk assessment group. The sum of all identified hazards plus m determines the overall membership of the threat assessment group.

5.3.2 A broad assessment

The measures of each group member are combined into a single fuzzy value for risk analysis using the fuzzy arithmetic mean, which is defined as:

$$RP_i = \frac{1}{m}\sum_{n=1}^{m} RP_i^m = \frac{1}{m}.(RI_i^1 \oplus RP_i^2 \oplus \ldots . \oplus RP_i^m \quad (6)$$

$$RI_i = \frac{1}{m}\sum_{n=1}^{m} RI_i^m = \frac{1}{m}.(RI_i^1 \oplus RI_i^2 \oplus \ldots . \oplus RI_i^m \quad (7)$$

5.4 Fuzzy Assessment of The Risk Factor

After providing the values RI & RP as fuzzy integers, the equation below can be used to compute the health hazard for each risk:

$$RF^{i} = RP^{i} \otimes RI^{i} \quad (8)$$

where each detected hazard is represented by I and $\otimes$ the fuzzy replication.

5.5 Defuzzification

Defuzzification is the process of changing a fake number into an actual one. Numerous approaches, including the centroid method, have been suggested for the defuzzification process [60].

$$(RF_i)_T = \frac{\int_0^1 xRF_i(x)d(x)}{\int_0^1 RF_i(x)d(x)} \quad (9)$$

5.6 Categorisation Of Risks

Threats are categorised based on hard impact factor as the final step in the risk analysis. The types and hazards that have been recognized are as follows:

- If $(RFi)_T$ ϵ[0, 0.1], Ri fits the category i and is classified as "Negligible."
- If $(RFi)_T$ ϵ[0.1, 0.4], Ri fits the category II and has a "Acceptable" rating.

- If $(RFi)_T$ ϵ[0.4, 0.8], Ri is assigned to group III and is categorised as "Non Acceptable."
- If $(RFi)_T$ ϵ[0.8, 1], Ri is categorised as "intolerable" under category IV.

Ting ting GAO created a fuzzy integrated on evaluation on HAZOP in an effort to overcome some of the issues of HAZOP, such as its inability to determine how important certain qualities are for the device. Running in the usual way. The most effective risk mitigation strategy must be created based on importance of the measures because HAZOP studies typically require a significant number of personnel, materials, and financial resources and because not all of the suggested actions can be followed due to lack of resources. Although LOPA or the analytic hierarchy method, as well as the HAZOP risk assessment and risk matrices technique, A process system's internal security within the work process is still unknown. despite the fact that they have been utilised in semi-quantitative assessments of processing industries safety [61, 62]. The fuzzy comprehensive evaluation approach was developed to look into the overall security of some nodes. Combining qualitative and quantitative information is a type of data analysis. The accuracy of each index's weight vector is determined by the aggregate knowledge and expertise of the experts, but it may unmistakably show the entity's integral safety.

HAZOP & fuzzy comprehensive assessment are combined to accumulating analyse the degree of impact of each factor on the state's regular output or integral safety. For requires a certain level evaluations and also chemical process network security evaluations, the fuzzy thorough overview centered on HAZOP analysis is used.

6. FUZZY LOPA

Only a semi quantitative risk assessment tool, Layer of Protection Analysis. This method makes use of information on hazardous occurrences, severity, initiating causes, and initiating probabilities from the Operability research. Based on the severity and likelihood of a broad range of hazardous events, users of the LOPA approach can calculate the risk that goes along with it. The user can evaluate the entire amount of hard decrease necessary and the lower risk that can be reached through several protection layers utilising corporate risk standards. If measures to reduce the risk are needed in addition to those provided by alarms, fundamental control systems, and process design and the human actions that go along with them, pressure-relieving valves, etc., there may be a need for safety instrumented functions. All risks cannot be totally eliminated by a single method. Therefore, some techniques must be applied to reduce the likelihood of a disaster. Protective layers are a collection of safety measures designed to lower risk by lowering the likelihood that future occurrences may have detrimental consequences on people, the lowering the intensity of an effect should an event occur. The Autonomous Protection Layers are shown in Fig. 11.

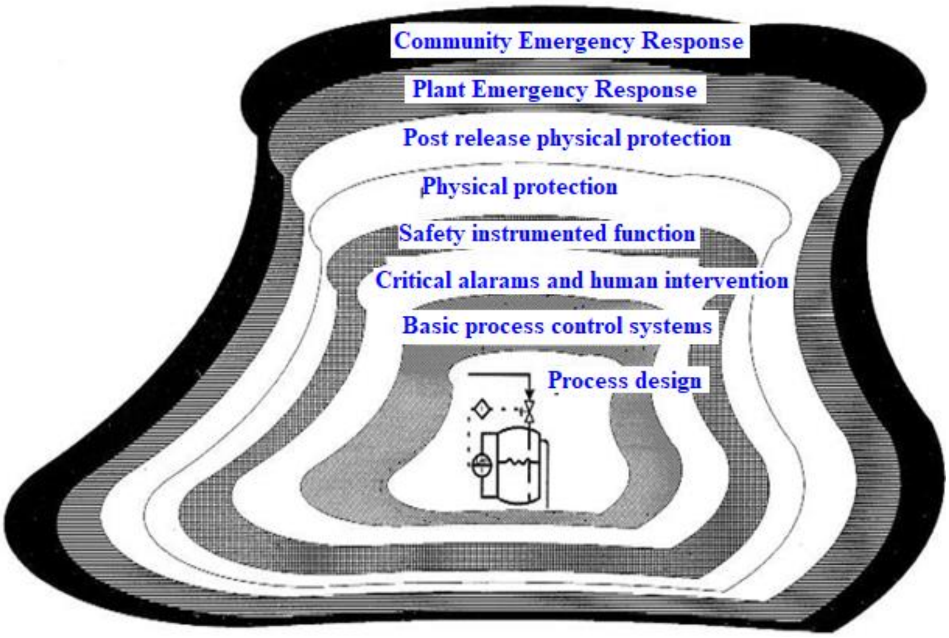

Fig 11: Independent Protection Layers

If risk reduction measures are needed in addition to those provided by the design process, fundamental process control systems, alarms and the operator actions that go along with them, pressure-relieving valves, etc., the Safety Instrumented Function may be required. All risks cannot be totally eliminated by a single method. Therefore, To lessen the chances of an accident, various methods must be used. Layers are a group of safety precautions intended to reduce hard by lowering the chance that future occurrences would have negative effects on people, the reducing the severity of an impact should an occurrence emerge. Figure 11 depicts the autonomous protection layers.

The following mathematical formulas represents the quantitative representation of LOPA; it raises the probability of an initiating event even by a small amount, preventing each individual protection layer from performing its aimed function: [63].

$$F_i^c = IEF_i \times PFD_{i1} \times PFD_{i2} \times \ldots \times PFD_{ij} \qquad (10)$$

where:

F_i^c = The frequency at which the outcome of the situation takes place; the usual measurements are annually (Low Demand) or per minute (High Demand).

IEFi =The IE rate for scenario i., PFDij = Independent Protection Layer J failure likelihood in scenario I.

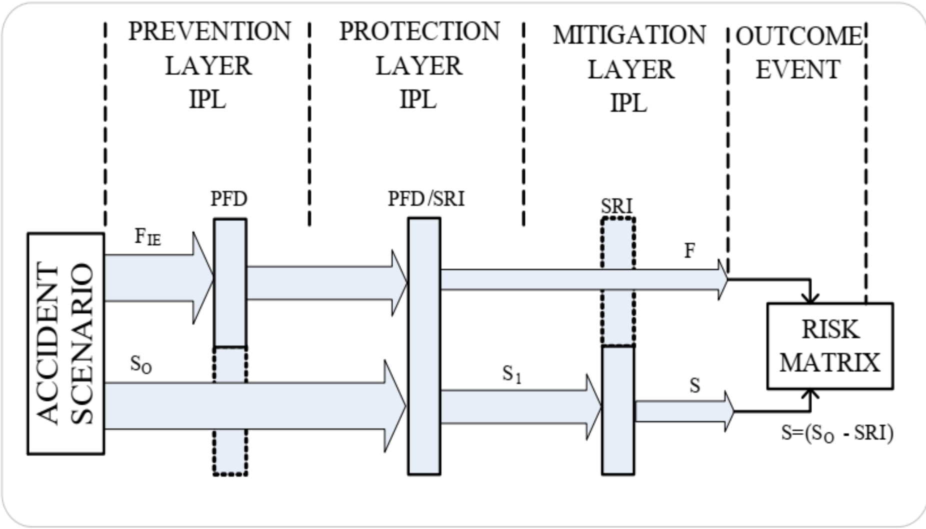

Fig 12: Function of protection layers in LOPA

In figure 12 LOPA model is a simple one that examines a single scenario of cause-and-effect linkages. Failure rate data was used in the majority of situations due to a lack of available data. Due to these factors, the risk of a negative outcome was typically high. More IPLs are needed when there is a significant risk, which results in greater installing and maintenance expenses. A point value in traditional LOPA has no uncertainty information and is used to generate single data point rates and upper bounds for periods of failure rates. Databases include the Offshore Represents the Data Handbook and the Center of Chemical Process Safety. Mean values with uncertainty information are necessary for increased accuracy. The best scenario for eliminating uncertainty is to gather sufficient plant-specific information to determine precise failure rates. On the other hand, developing a thorough data collection system for such a facility has proven to be both time- and money-consuming and impractical. Other issues include the assumption that while separate protective layer's function, the severity of the repercussions would remain constant, as well as their limited availability and the unpredictability of their failure rates. These problems are addressed by the fLOPA. When there is a paucity of information on dependability information, such as the probability that an event will begin and safety systems, fuzzy logic may be used. As demonstrated in Figure 12, the technique is utilised to determine a risk model. As can be seen, the preparedness and protection layers had an impact on the seriousness of the consequences, whereas the preventive or protection layers alone had an effect on the total frequency of outcomes (F) (S). The severity reduction index (SRI), a unique index, has been employed for this.

A fuzzy logic-LOPA technique was presented by [64] to deal with data imprecision and ambiguity. The use of linguistic fuzzy modelling in this study makes use of fuzzy sets and if-then rules. The use of fLOPA is initiated using the event scenario data, which is followed by the application of three subsystems. A precise risk for the given scenario is the result. The standards, literature data, and expert judgement are used to construct the fuzzy inference systems. Based on these findings, the linguistic variables and their correlations are identified. The definition membership algorithms, fuzzy sets, follows. The fuzzy sets of the fuzzy system serve as representations for the linguistic variables. The If-Then rules are then created using the Mamdani model to describe the system's general knowledge [65]. The three subsystems listed below correspond to those in Figure 13:

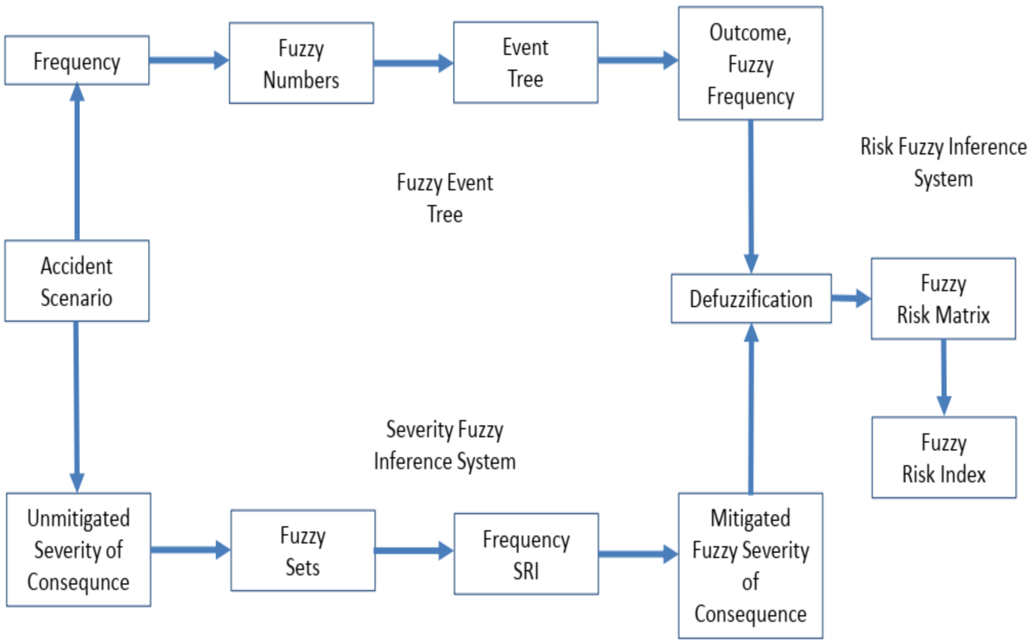

Fig 13: Fuzzy LOPA structure

• Employs a fuzzy event tree to determine how frequently the accident scenario occurs.

A clear risk index is produced by the Risks Fuzzy Inference System, which can be utilised to guide decision-making.

• The Severity Fuzz Inference System determines how a situation is affect that.

To analyse the same ambiguity in LOPA, as well as to verify a mean and precisely measure the same unpredictable nature of intensity of an starting an action and the likelihoods of failure upon request of unbiased protection layers, [66] proposed a combination fuzzy logic and stochastic using a method on expert elicitation decision and literature.

For assessing the risk in the natural gas industry, [67] developed the cascaded fuzzy -LOPA method. The product's severity and frequency coupled produce risk.The influence just on company's safety & financial factors is used to determine the severity of the each incident. Each component is assigned a severity rating based on risk matrix. This study focused on two techniques: the first one was estimating the severity of a scenario, as well as the second is determining the SIL need based on the hard. Both techniques are prepared using the fuzzy logic concept. They have used MATLAB toolkit to simulate the results. Mamdani model, among the most often used fuzzy models, [68] was utilised. The Mamdani fuzzy model contains techniques for giving parameters under consideration crisp values, fuzzifying that crisp data, creating a series of the If rules designed to obtain outcomes in such a fuzzy form, and ultimately defuzzifying that fuzzy output to provide crisp output.

Cascade fuzzy-LOPA has once more been recommended by [69] for risk analysis of LNG regasification plants. The safety and economical severity levels are employed to calculate the overall severity in this study, which uses fuzzy logic in two steps. The total fuzzy severity is obtained by applying fuzzy here between fuzzified intensity value and the fuzzy bandwidth value after the clear values of economic severity and safety have been defuzzified to obtain the crisp value. The overall fuzzy risk is then calculated by adding fuzzy between the fuzzy severity variables and the fuzzy frequency value. A fuzzy hard value is converted into a crisp risk value using the fuzzy inference technique (FIS). In a fuzzy method, variables like fail frequency, security severity, and economical severity are assigned using a Gaussian membership function, and hard is calculated using if-then logic.

7. FUZZY BAYESIAN NETWORK

In actuality, networks with a fuzzy risk value are transformed into a crisp hard value using the fuzzy inference technique. In a fuzzy method, variables like failure frequency, safety severity, and economic severity are assigned using a Gaussian membership function, and risk is calculated using if-then logic. For the purpose of statistical modelling, there is a formalism that provides a solid and superior framework for deliberating about ambiguous data. Simply put, a BN is a DAG with the nodes standing in for significant method variables and the arcs representing their cause-and-effect connections. In order to factorise variable joint probabilities, BN uses conditional dependencies. Calculating the prior probability of numerous variables is the main purpose of BN. The properties of BNs are a collection of nodes with directed arcs, a prior probability table P(X) linked to the father node X, and a conditional probability table P(Y/X) linked to the node Y whose father is X. Given the states X, it defines the prior likelihood across the states of Y.To obtain a trustworthy global assessment, BNs enable the combination of data from observations, response expertise, evaluation process, evaluation of the studied entity or company , and evaluation. These data sources are typically necessary to create the model. However, because there aren't enough feedback experience data, particularly in areas like reliability, risk analysis, or maintenance, the current study's construction of the models' structure was mostly dictated by expert judgement. For the purpose of assessing risk for power plant projects, a fuzzy-Bayesian model was created by Muhammad Saiful Islam. The Bayesian network is used to capture these same intricate relationships between risks and to update the model using the most recent data. The most recent data is utilised to update the model and the Bayesian network is employed to collect the intricate relationships between the hazards. The potential hazards for the project have been classified using expert opinion elicitation. In figure 14 shows that the Fuzzy Bayesian belief network model for risk assessment has been illustrated.

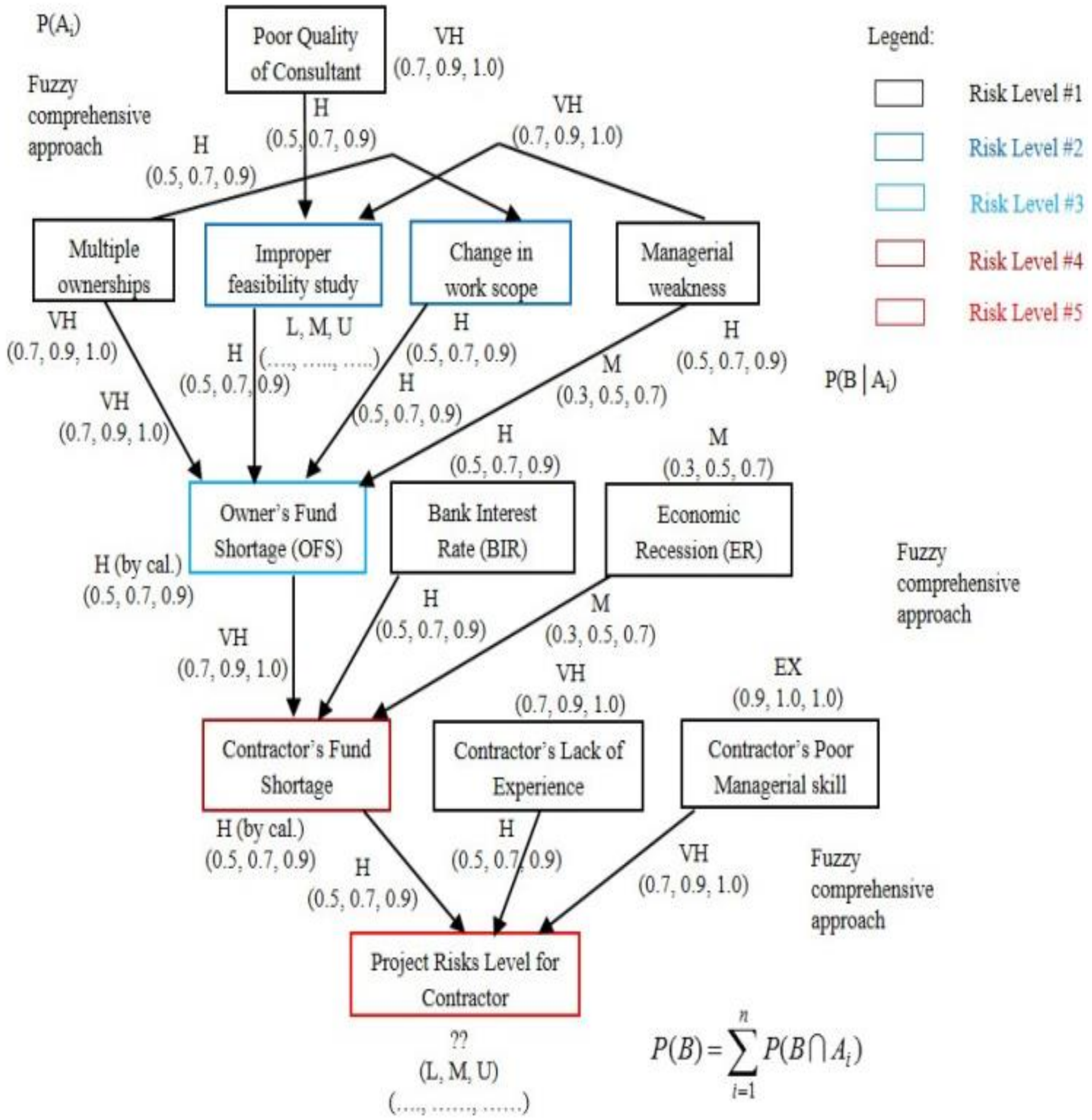

Fig 14: Fuzzy-Bayesian belief network model for risk assessment

On a range from extremely high (EVH), very high (VH), high (H), moderate (M), low (L), very low (VL), and very low (EVL), five experts were asked to assess the level of hard for separate risk factors (those without parents) (EL). They were once more given instructions to use the same quality nomenclature, i.e., EH to VL, to link the hard and the considerable level (impacts upon following risks). The Bayesian belief capacity utilisation is used to calculate the likelihood of the dependent hazards. Probability and conditional probability, which make up the two halves of the Bayesian belief technique, are successively computed from the hard levels of account and the consequential levels from earlier hards on subsequent hards utilising a fuzzy, all-inclusive team decision-making strategy. The likelihood of the dependent hazards is determined using the Bayesian belief capacity utilisation. Probability and likelihood of an event, which make up the two halves of the Bayesian belief technique, are successively computed from the relative risks of account and the consequent levels from earlier chances on subsequent risks utilising a fuzzy, all-inclusive team decision-making strategy.

Fuzzy Bayesian Network was developed by [70] to deal with uncertainty more effectively (FBN) has been shown in figure 15. The establishment of probabilities was done utilising fuzzy theory and expert elicitation. FBN delivers more complete, transparent, and realistic results than BN, according to a comparison between the two methods [71].

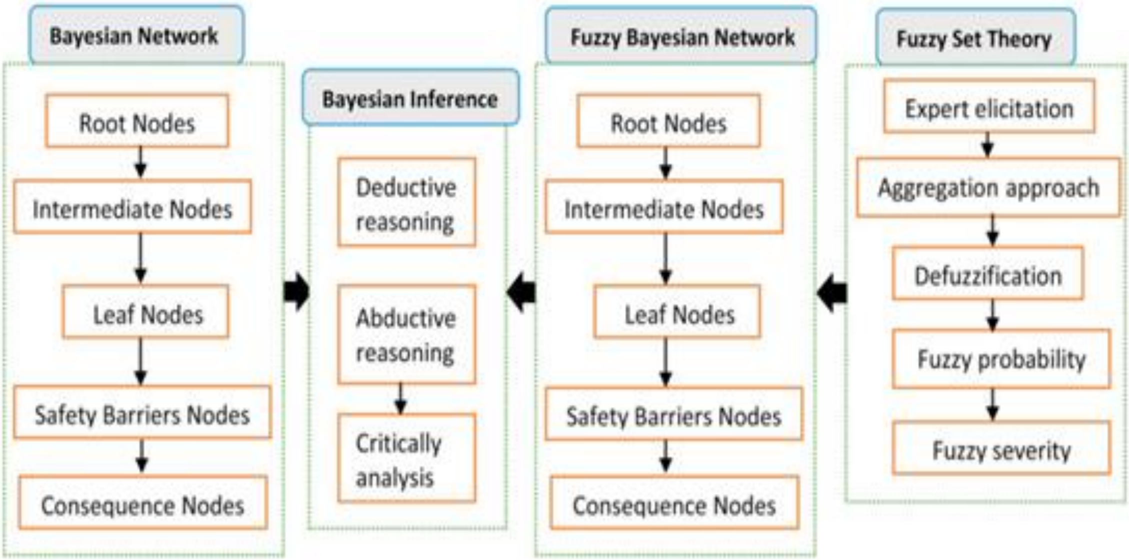

Fig 15: An approach to safety risk analysis based on FBN

In order to evaluate the possibility of core occurrences, retaining walls, and the seriousness of repercussions in the face of ambiguity, expert elicitation and fuzzy logic were applied. It shows how BN and fuzzy logic can be combined to overcome both approaches' drawbacks in process safety evaluation.

8. FUZZY RISK MATRIX

Risk is the phrase used to explain the link between the possibility of something happening and the fear of the consequences). The loss and severity that an organisation suffers as a result of a risk incident are known as the risk consequence [71]. It classifies and ranks the severity of impacts using category ratings, such as "very low, weak, medium, high, and very high" or "insignificant, minor, moderate, enormous, and catastrophic". Risk likelihood is a term used to describe the likelihood that something will happen, and it is often expressed using a category scale. The probability has been labelled as "rare, unlikely, plausible, likely, and almost definite" in studies. The semi-quantitative risk matrix's two input variables are the likelihood of occurring and the severity of occurrence. The major inputs of the fuzzy risk matrix are the frequency or severity of the outcome of an incident scenario. When fuzzy rules are developed utilising different risk matrix designs, the only risk that results are a defuzzified risk. In figure 16 shows that the risk matrix has been demonstrated.

Likelihood				
4	M (4)	M (8)	H (12)	H (16)
3	M (3)	M (6)	M (9)	H (12)
2	L (2)	M (4)	M (6)	M (8)
1	L (1)	L (2)	M (3)	M (4)
	1	2	3	4
	Consequence			

Fig 16: Risk matrix

8.1 Development of a Fuzzy Risk Matrix

The Traditional Risk Rating was created using fuzzy logic to deal with ambiguity (FL). FL is competent of handling Clarity, imprecision, and problem-solving issues without having boundaries that are well defined. According to fuzzy logic, fuzzy sets are the equivalent of traditional independent variables for specific linguistic elements like frequent, severity, and risk. The fuzzy sets were made using the variable categories. x is a membership function that compares values between [0, 1] ranges. defines a fuzzy set on the space of speech. The fuzzy subset can be compared to an element in U using a statistic known as a membership function. Fuzzy risk matrixes are created using the fuzzy logic approach. The following elements make up the FLS:

1. Crisp input is transformed into fuzzy sets via the fuzzifier. Fuzzification builds appropriate fuzzy sets according to fuzzy set principles for each element of the hard matrix.

2. The FLS inference engine transforms input fuzzy sets into fuzzy output sets by applying a set of rules. It is worried about how laws are put together. This set of rules is produced via a series of IF-THEN statements using technical data. It enables a hazy risk assessment.

3. In reality, defuzzification entails weighing and averaging each of the several outputs from fuzzy rules into a individual output rating. This risk index's output selection was exact, defuzzified, and had a certain benefit.

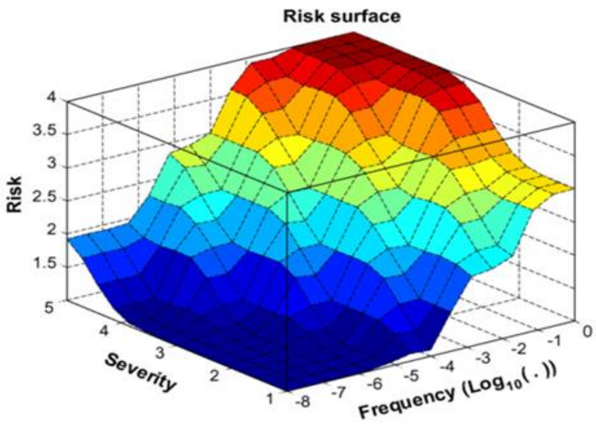

Fig 17: Fuzzy risk surface standards

A 3D figure 17 that depicts the mappings between two signals (frequency and severity) with one output can be used to indicate the link between frequency, severity, and risk. A fuzzy risk matrix was presented by [72] as a means of estimating the likelihood of air traffic incidents. The paper proposes a method for assessing risk that expresses danger as a constant range of numbers. As a result, a fuzzy risk matrix that uses linguistic factors to describe both the probability of an activity taking place and how bad the results will be has been proposed. The risk assessment was carried out via a fuzzy inference system, and the implications were also calculated using expert fuzzy inference rules that were computer-implemented. A accurate assessment of the risk of a traffic problem similar to a Terminal Incursion developing into an accident was made possible by experiments employing this method. Additionally, this grade may be elevated to insufferable if poor visibility circumstances are coupled with a high number of event participants who react slowly.

In [73] examined risk indicators in order to evaluate the likelihood of safe operations for hazardous goods in airfreights (RFs). To evaluate the risks associated with RFs, a novel hard matrix built on the fuzzy AHP is being developed. Respondents are required to assess each RF in a typical risk matrix independently based on their opinions. On a category scale, the effects and likelihood are both measured. It could be challenging for the refer to accurately score an RF in such a direct grading criteria. While using a grading system that is almost identical to one another may make it simpler to analyse the consequences or likelihood levels of an RF, This research employs a fuzzy AHP procedure, This evaluates the RFs using a similar scoring system. This strategy can improve the accuracy of topic measurements, which is improve the risk matrix's performance.

9. FUZZY EVENT TREE ANALYSIS (FETA)

An accident-causing hypothetical sequence of events is constructed using the underside, inductive, forward reasoning method of event tree analysis, which begins with an initiating incident. It is helpful for analysing beginning events that might result in a number of different outcomes. Although it was initially created for the aerospace & automotive sectors, Nowadays, in the chemical and nuclear sectors, it is also employed.

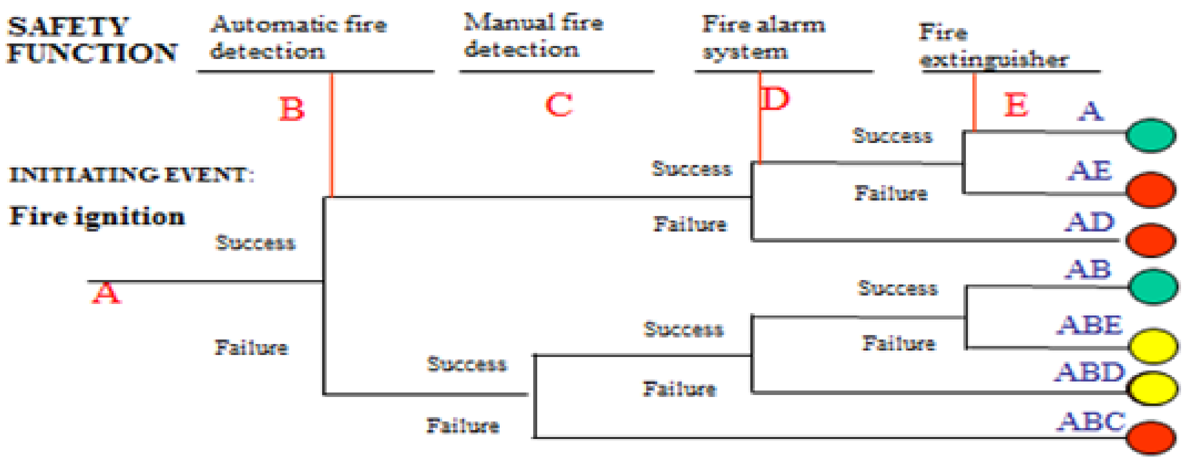

Fig 18: Structure of Event Tree Analysis

As shown in Figure 18, a series of episodes commonly reflect necessary functions and barriers after an unsafe event. The event trees are then converted to binary trees, where each branch represents whether a safety action was successful (true) or unsuccessful (false). There is a (P) failure probability if an event has a (P) success probability (1-P). Event trees can be analysed quantitatively and qualitatively. A qualitative study of an event log is used to determine the likely consequences of the first occurrence. Quantitative FTA is used to calculate the likelihood of a possible outcomes of a initial event. In [74] goes over how to design and analyse events trees for critical processes in great depth. Because they illustrate how to combine probability and event sequences' effects, event trees are excellent for determining the risk and reliability of systems. Because of the ambiguity or imprecision in the informations, and consequently the range of numbers, it can be challenging to estimate both probability and impacts of a single number. The fuzzy probabilistic approach solves this issue since it uses a range of values to predict the likelihood of a particular result, which can handle uncertainty. In [75] suggested a fuzzy hybrid event tree technique to evaluate the probable radioactive risks during nuclear reactor decommissioning. A normal distribution is used to describe the membership function of the experts annotation as a state of a basic variable. The old unique numbers used to indicate probability have been replaced by fuzzy numbers.

Refaul Ferdous contrasts Monte Carlo simulation with fuzzy set theory and evidence theory as two techniques for resolving unknowns. The proposed fuzzy technique was utilised to cope with subjectivity or imprecision; nonetheless, evidence theory is applied when dealing with inaccurate data. The following are the stages for the fuzzy based ETA [76-79]:

1) Utilize fuzzy trapezoidal integers to calculate event probability (TFN)

2) Identify the probability of the outcome of the event.

3) Demystify incident frequency results.

An event tree analysis in uncertain environments has been demonstrated in figure 19.

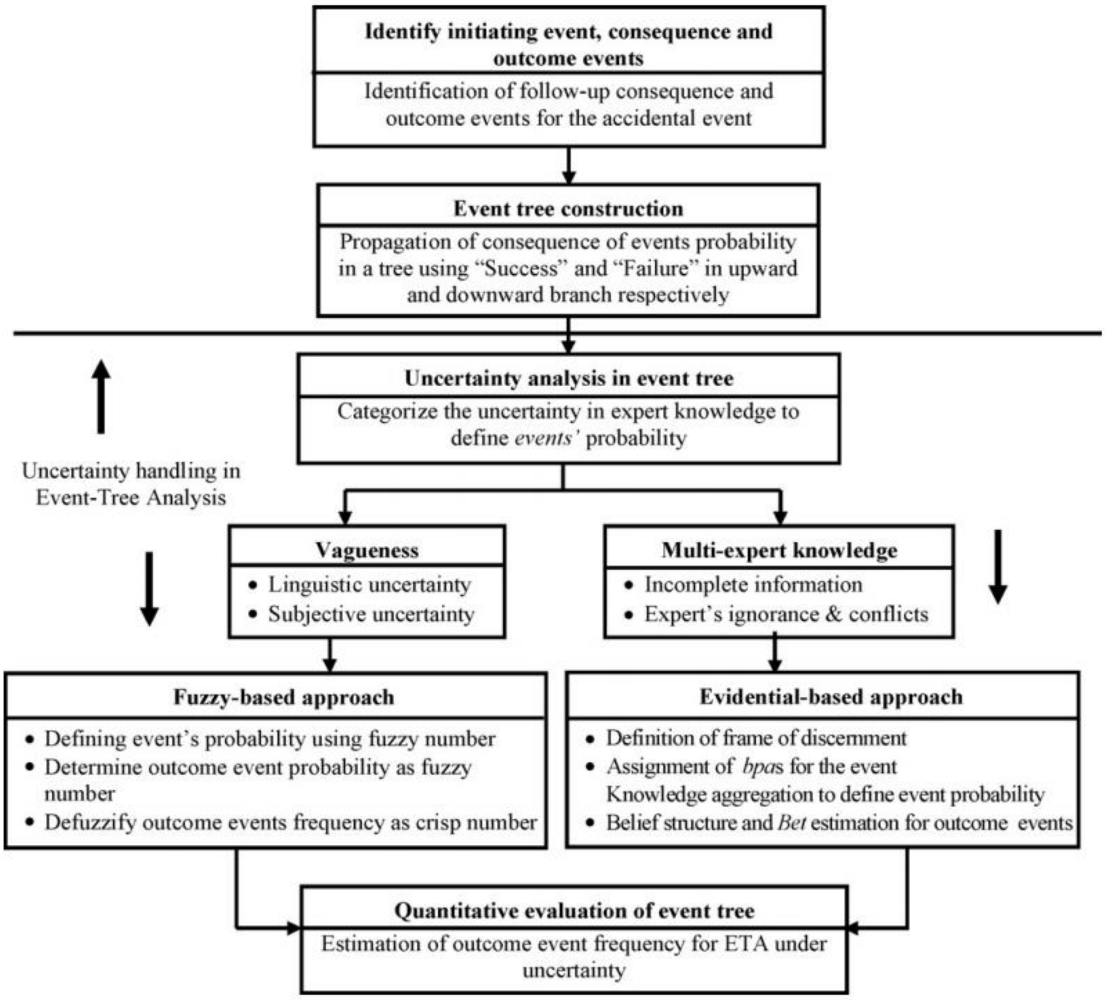

Fig 19: Event Tree Analysis in Uncertain Environments

10. OTHER APPROACHES

Other methods of risk analysis that employ fuzzy logic to account for process uncertainty include bow-tie analysis, intuitionistic fuzzy, Markov models, and petri nets.

10.1 Fuzzy Bow-Tie Analysis

A statistical technique for evaluating the chances and trajectories of occurrences in disaster scenarios is known as bow-tie analysis. In to prevent, manage, or minimize adverse events, establishing a logical connection between their effects and causes is its main objective [80-83].

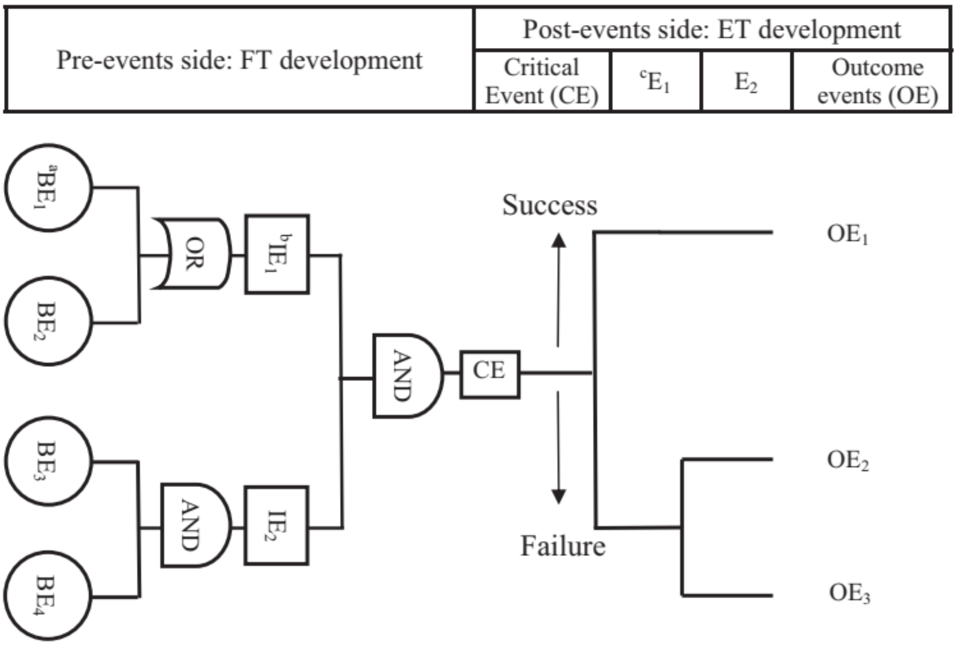

Fig 20: The Bow-Tie Diagram's component

The following are the bow tie's five components: 2) Leads to Fault Tree (FT) 3). The Events under Emergency Conditions (CE) (ET) 5) Scenarios that come from a decision (OE) Figure 20 depicts the links between the various parts. In order to estimate the danger associated with oil and natural gas pipelines, [84] developed a fuzzy based neck analysis. The "bow-tie" method combines a fault tree (just on the left) with only an event tree (just on the right) to portray causes, threats, or effects on a single platform (on the right). Model uncertainty was produced by the independent condition of risk occurrence and was not diminished by the traditional "bow-tie" method. To deal with the ambiguity of the informations, fuzzy logic is utilised to compute fuzzy likelihood for standard events within fault trees or to compute fuzz probabilities for output results of an event. The research proposes the fuzzy utility value (FUV) as a tool for doing triple bottom line risk analyses for natural gas pipelines and also investigates if interdependencies between various factors may have an impact on analytical results (TBL). Traditional "bow-tie" analysis assigns precise probability to fundamental risk occurrences (for FT) or events (for ET), even if it can be challenging to determine some probabilities due to a lack of statistical information and understanding. As a result, such a high likelihood may provide "precise" yet unlikely results. In their investigation, they used fuzzy linguistic probability (p). These make it possible to disperse uncertainty throughout the entire "bow-tie" structure. The risk of failure (TFN) is calculated using the failure likelihoods given by a trapezoidal fuzzy value. In this context, the following events are occurring: Fuzzy failure likelihoods and related alternatives are used in "bow-tie" analysis in place of crisp probability [85-87].

10.2 Fuzzy Markov Chain Approaches

A graphical modelling method called Markov models analysis, which is based on state transitions, may represent a system's behaviour in a dynamic state. In a typical Markov model of a system, all of the system's potential states, transitions between them, and numeric showing how quickly each transition takes place are all included. The Markov model for safety and reliability analysis includes states for equipment breakdown, failure patterns and spare resource allocations. The components repair or breakdown rates are the transition rates. With this datas, differential formulas for states are produced, and by resolving these formulas, solutions are obtained. Accurate transition rates and probabilities are presumptions made in conventional Markov chains. In [88-92] fuzzy Markov chain techniques were suggested as a solution to uncertainty. These methods allow for the possibility of ambiguous transition rates, probabilities, and states. In Markov models with fuzzy transition rates, system reliability is estimated using two different methods. When transition rates were very unpredictable in the first case, fuzzy membership functions were introduced to the matrix using Markov equations. The computation of the Markov process is then finished using fuzzy arithmetic methods. Since this system demands sophisticated calculation with fuzzy numbers, it presents a technological challenge [93-95]. The second method uses transition rate functions to create reliability indices, which are then applied to fuzzy data to assess fuzzy reliability indices. This tactic's requirement for exact mathematical equations might be challenging in large systems with intricate component interactions. In figure 21 shows that the risk assessment for natural gas pipeline failure in the presence of uncertainty

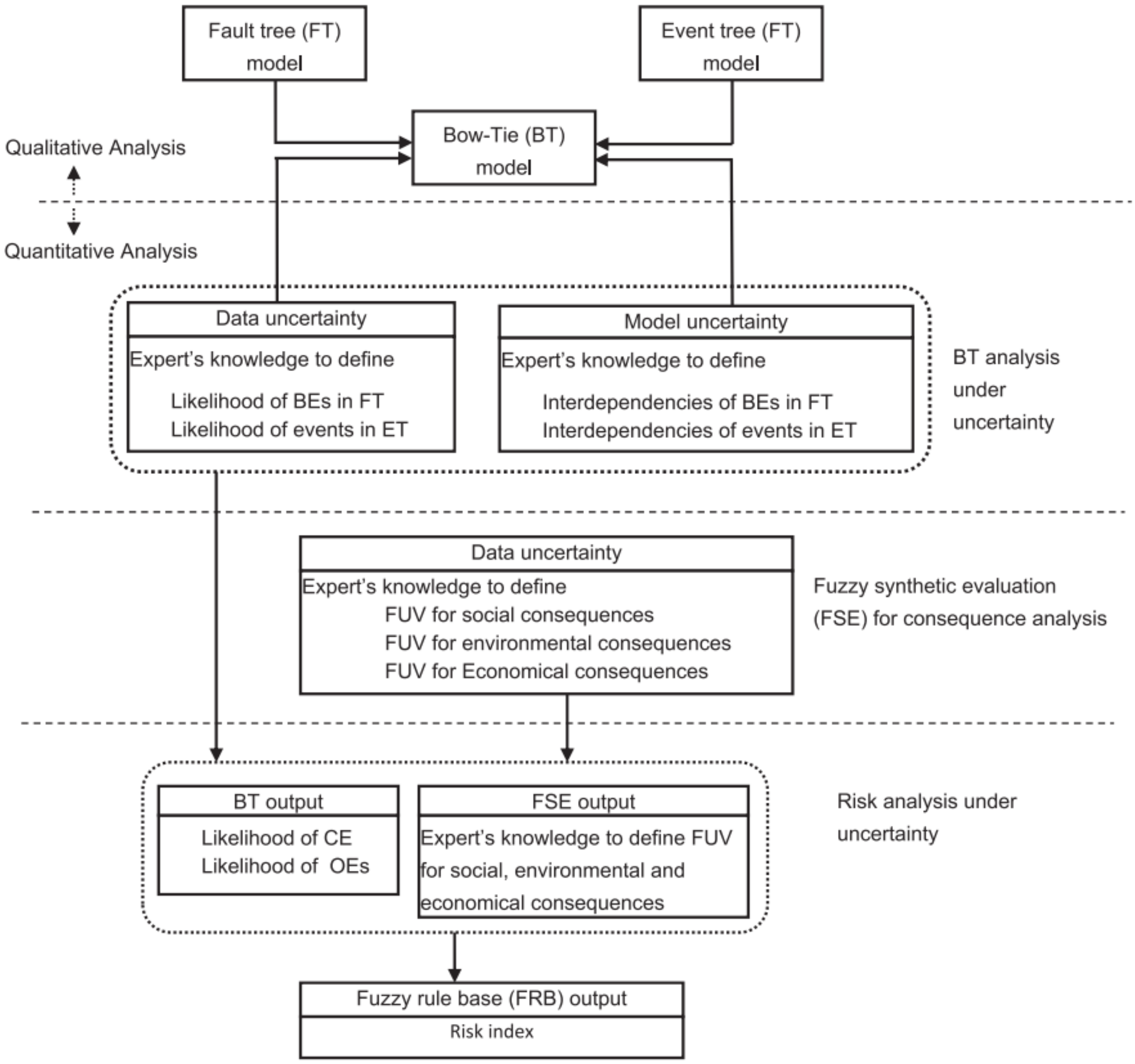

Fig 21: Risk assessment for natural gas pipeline failure in the presence of uncertainty

11. ADVANTAGES OF FUZZY IN RISK ANALYSIS

The method's reduced computational complexity is its main benefit. It has been proven that the new method is more prevalent when it comes to solving difficulties involving risk analysis because it is simpler and more effective. Risk analysis techniques are powerful tools for helping people deal with uncertainty. Contrarily, qualitative techniques like scenario analysis, fuzzy set theory (FST), etc., rely more on judgement than statistical calculations. Both quantitative and qualitative methods have benefits and drawbacks. Among these methods, the use of FST in risk analysis seems acceptable given that this type of study is extremely subjective and dependent on unreliable and ambiguous data [96].

For hazards without an appropriate quantitative probability model, a fuzzy logic system can assist in modelling the cause-and-effect relationships, assessing the level of risk exposure, and ranking the major risks continuously while taking into account both the data available and the viewpoints of experts. Systems are described by fuzzy logic using a combination of linguistics and mathematics (symbolic). Because system information is frequently available in such a combination, compared to pure symbolic or mathematical methods, it has advantages.

Issues for which an exact theoretically accurate description is missing or is only available in extremely specific situations can usually be solved if a fuzzy model is present. Because fuzzy logic occasionally only uses approximations, simple sensors can be used. Little data is needed to describe the algorithm. For hazards without an appropriate quantitative probability model, a fuzzy logic system can assist in modelling the cause-and-effect relationships, assessing the level of risk exposure, and ranking the significant risks continually while taking into account both the available data and the opinions of experts.ms, so memory usage is minimal. The algorithms are frequently very clear. Insofar as they are not very sensitive to changes in the environment, fuzzy algorithms are frequently robust settings, and outdated or inconsistent rules. Comparing the reasoning process to computationally exact systems, it is frequently straightforward. Saving computer resources particularly for real-time systems, this is a really intriguing aspect. The creation of fuzzy methods typically takes less time than that of traditional approaches.

12. DISADVANTAGES OF FUZZY IN RISK ANALYSIS

Crisp-Input/Crisp-Output systems are one example of this fuzzy logic is equivalent to function approximation. This indicates that applying fuzzy logic is frequently just a different method of performing interaction. This method might even be helpful given that system knowledge is frequently available as a combination of quantitative numbers and quantitative or qualitative linguistics. When there are too many constraints on computer capacity (i.e., time and memory) for a thorough mathematical implementation, fuzzy logic is frequently a useful alternative in domains with adequate mathematical descriptions and solutions [97].

13. APPLICATION OF ADVANCED TECHNIQUES IN RISK ANALYSIS

Artificial intelligence (AI) enables inanimate objects powered by computers to think and behave like people. The study of AI focuses on how the human brain makes decisions, learns, and thinks. The goal of the large field of AI is to build intelligent machines. AI's machine learning (ML) division identifies and learns various data set patterns. According to its definition, ML is an application of AI that frees systems from implicit programming and enables them to learn spontaneously and get better with practise. Machine learning typically employs neural network models, support vector machines decisions trees, random forests, logistic regression, and many more methods (ML). Additionally, a few others, such the generative adversarial network, are divisions of the neural network.ML is in charge of employing a machine learning approach to analyse the data acquired while driving and identifying unsafe behaviours using the accelerometer and gyroscope data. These actions result in abrupt changes to the motion state. Seven cutting-edge algorithms were thoroughly analysed in order to choose the one that best represents risky behaviours with the highest degree of accuracy. In order to optimise circuit design, fuzzy inference systems analyse the behaviour of electrical circuits. They can be used to model the response of electrical circuit variables and assess the influence of circuit parameters on an output response simultaneously. Circuit optimization has a number of drawbacks as a result of the nonlinearities in the response-affecting components. The incorporation of tolerances into the circuit's component sections also has an impact on how complex the resulting equations are. The optimised values cannot be workable due to component tolerances and potential circuit instability, similar to how utilising optimization techniques without input from the design process may result in unworkable solutions.

14. CONCLUSION

50 years ago, there were about 3.5 billion people on the planet; today, there are 7.9 billion people. The population density has increased dramatically. Numerous new industries, such as petrochemical products, oil and gas, automobile, nuclear, aviation, industrial, defence, pharmaceuticals, and mining, are developing as a result of rising human needs and technological advancements. These rapid industrializations have resulted in a rise in risks and accidents [98]. The world's worst industrial disasters include three-mile island, the Chernobyl catastrophe, Mexico City, the Flixborough accident, the Oppau Explosion, and the Halifax Explosion; the Bhopal tragedy; to name just a few. The importance of safety becomes apparent in this situation. Every business has a duty to safeguard people, machinery, and equipment. Furthermore, environmental protection is essential in today's globe. China, the US, and India are the top three carbon dioxide emitters; maintaining sustainability is another challenge for business. 4000 people have died as a result of the Bhopal tragedy, and many more fatalities go undetected. Structured risk assessment processes can locate possible dangers and examine their causes and effects. This will help to avoid similar incidents in the future. Quantitative as well as qualitative methodologies are used in risk assessment. Failure Mode Effect and Criticality Analysis (FMECA), Layer of Protection Analysis (LOPA), Hazard Operability Analysis (HAZOP), Failure Mode Effects Analysis (FMEA), Bayesian Networks, Bow-Tie Analysis, and such are some instances of fault tree analysis. This method is challenging and imprecise, resulting in inaccurate projections of probable disaster situations in the future due to a lack of accident data sets, inaccurate data, or differing degrees of expert qualitative opinion. The uncertainty is being reduced by the application of fuzzy logic. Fuzzy sets allow no clearly defined bounds due to the generalisation of a scaling factor to a membership value, and fuzzy inference systems provide a mapping from an input signal to an output. The four crucial parts of a fuzzy system are the fuzzyifier, information, inference system, and defuzzification. In this research, looked at fuzzy fault tree analysis, fuzzy HAZOP (FHAZOP), fuzzy FMEA (FFMEA), fuzzy FMECA (FFMECA), fuzzy HAZOP (FHAZOP), fuzzy Bayesian network (FBN), fuzzy LOPA (FLOPA), fuzzy risk matrix (FRM), fuzzy event tree analysis (FETA), fuzzy markov chain, and fuzzy Bow-Tie Analysis.

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