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Fuzzy consequence modelling of hydrocarbon offshore pipeline

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ABSTRACT: The traditional event tree analysis uses a single probability to represent each top event. However, it is unrealistic to evaluate the occurrence of each event by using a crisp value without considering the inherent uncertainty and imprecision a state has. The fuzzy set theory is universally applied to deal with this kind of phenomena. The main purpose of this study is to construct an easy method to evaluate human errors and integrate them into event tree analysis by using fuzzy concepts. A systematic fuzzy event tree analysis algorithm is developed to evaluate the risk of a large-scale system. A practical example in of offshore oil pipeline is used to demonstrate this procedure.

Keywords: *Event Tree Analysis (ETA), Fault Tree Analysis (FTA), Fuzzy Event Tree Analysis (FETA), Fuzzy Importance Measure (FIM), Fuzzy Uncertainty Importance Measure (FUIM)*

INTRODUCTION

Event Tree Analysis (ETA) is an inductive logic and diagrammatic method for identifying the various possible outcomes of a given initiating event. For an initiating event, if two-state modeling is employed (one failure state and one success state), then an event tree can be constructed as a binary tree with nodes representing a set of possible failure and success states. In conventional ETA, system failures that cause these events are analyzed by using Fault Tree Analysis (FTA) to identify the interrelationships between systems and components. The failure rate of a component is treated as a random variable and often lognormal probability density function is used to describe the failure rate variability and uncertainty. Through FTA quantification, lognormal probability density functions of component failures are modeled by Monte Carlo simulation to determine the whole system failure rate. The output often contains the median, 5% and 95% percentiles of the occurrence rate. After getting these valuable data, only the median value will be incorporated into the ETA, and a lot of information about the range of uncertainty is lost through this procedure. However, the whole state of a system often has uncertainty involved, it is incomplete using one value to represent a fuzzy state. Sometimes a system can still function with some failed components. Therefore, the fuzziness of the system state comes from the states of its components and other factors (such as the operations performed by human) that can affect it. By considering the aforementioned issues, it is necessary to incorporate fuzzy system with ETA.

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MATERIALS AND METHODS

1.Fuzzy set theory

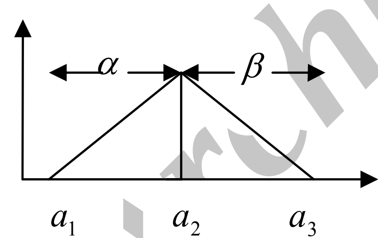
Classical set contains objects that satisfy precise properties of membership. Fuzzy sets, on the other hand, contain objects that satisfy the imprecise properties of membership (Zadeh, 1965), i.e. membership of an object in fuzzy set can be partial. For classical sets, element in a universe is either a member of some crisp set or is not. This binary issue of membership can be represented mathematically by indicator function:

$$X_A = \begin{cases} 1, x \in A \\ 0, x \notin A \end{cases}$$

Zadeh extended the notion of binary membership to accommodate various degrees of membership on the real continuous interval {0,1}, where the endpoints of 0 and 1 conform to no membership and full membership respectively. The sets of universe *U* that can accommodate degrees of membership were termed by Zadeh as fuzzy sets. Hence, a fuzzy set can be represented by functional mapping as $\mu_{\tilde{A}}(\chi) \in [0,1]$, where $\mu_{\tilde{A}}(\chi)$ is degree of membership of element χ in fuzzy set $\tilde{A}$ or simply membership function of $\tilde{A}$. The value $\mu_{\tilde{A}}(\chi)$ is on the unit interval that measures the degree to which element belongs to fuzzy set $\tilde{A}$; equivalently, it can be written $\mu_{\tilde{A}}(\chi)$ = the degree to which $\chi \in \tilde{A}$. The larger $\mu_{\tilde{A}}(\chi)$ is the stronger degree of belongingness for χ in $\tilde{A}$. In this study two special kinds of fuzzy numbers including triangular fuzzy numbers and trapezoidal fuzzy numbers are employed. A triangular fuzzy number (Left and Right fuzzy number) can be defined by triplet.

Definition 1 (Zimmermann, 1991): Let L (and R) be decreasing, shape functions from $R^+ = [0, +\infty]$ to [0,1] with $L(0) = 1$; $L(\chi) < 1$ for all $\chi > 0$; $L(\chi) > 0$ for all $\chi < 1$; $L(1) = 0$ or ($L(\chi) > 0$ for all χ and $L(\infty) = 0$). Afuzzy number $\tilde{A}$ is called L - R type if for α_2, $\alpha > 0$, $\beta > 0$ in $R = (-\infty, \infty)$.

$$\tilde{\propto}_A(x) = \begin{cases} L(\frac{a_2 - x}{\alpha}), for (x \le a_2, \alpha > 0) \\ R(\frac{x - a_2}{\beta}), for (x \ge a_2, \beta > 0) \end{cases} \quad (1)$$



Where α_2 iscalled the mean value of $\tilde{A}$, α and β are called the left and right spread, respectively. L_R type fuzzy numbers can be denoted by. $(\alpha_2, \alpha, \beta)$. Let $\tilde{A} = (\alpha_2, \alpha, \beta)$ and $\tilde{B} = (b_2, \gamma, \delta)$ be two triangular fuzzy numbers. With this situation, the extended fuzzy operation can be calculated as follows:

Change of sign: $-(\alpha_2, \alpha, \beta) = (-\alpha_2, \beta, \alpha)$ (2)

Addition $\oplus$: $(\alpha_2, \alpha, \beta) \oplus (b_2, \gamma, \delta) = (\alpha_2 + b_2, \alpha + \gamma, \beta + \delta)$ (3)

Subtraction -: $(\alpha_2, \alpha, \beta) - (b_2, \gamma, \delta) = (\alpha_2 - b_2, \alpha + \delta, \beta + \gamma)$ (4)

Multiplication $\otimes$: $(\alpha_2, \alpha, \beta) \otimes (b_2, \gamma, \delta)$
$\cong (\alpha_2 b_2, \alpha_2\gamma + b_2\alpha - \alpha\gamma, \alpha_2\delta + b_2\beta + \beta\delta)$ (5)

Division ÷ : $(\alpha_2, \alpha, \beta) \div (b_2, \gamma, \delta)$

$$\cong (\frac{a_2}{b_2}, \frac{a_2\gamma + b_2\alpha}{n^2}, \frac{a_2\delta + b_2\beta}{n^2}), \ if\ (m, n > 0) \quad (6)$$

Let $\tilde{A} = (\alpha_2, \alpha_3, \alpha, \beta)$ denote the trapezoidal fuzzy number, where $[\alpha_2 - \alpha, \alpha_3 + \beta]$ is the support of $\tilde{A}$ and $[\alpha_2, \alpha_3]$ its modal se.

Let $\tilde{A} = (\alpha_2, \alpha_3, \alpha, \beta)$ and $\tilde{B} = (b_2, b_3, \gamma, \delta)$ be two trapezoidal fuzzy numbers. The arithmetic on the proposed fuzzy numbers can be defined as follows:

Change of sign: $-(\alpha_2, \alpha_3, \alpha, \beta) = (-\alpha_3, -\alpha_2, \beta, \alpha)$ (7)

Addition $\oplus$: $(\alpha_2, \alpha_3, \alpha, \beta) \oplus (b_2, b_3, \gamma, \delta)$ (8)
$= (\alpha_2 + b_2, \alpha_3 + b_3, \alpha + \gamma, \beta + \delta)$

Subtraction - : $(\alpha_2, \alpha_3, \alpha, \beta) - (b_2, b_3, \gamma, \delta)$ (9)
$= (\alpha_2 - b_3, \alpha_3 - b_2, \alpha + \delta, \beta + \gamma)$

Multiplication $\otimes$: $(\alpha_2, \alpha_3, \alpha, \beta) \otimes (b_2, b_3, \gamma, \delta)$ (10)
$\cong (\alpha_2 b_2, \alpha_2 b_3, \alpha_2\gamma + b_2\alpha - \alpha\gamma, \alpha_2\delta + b_2\beta + \beta\delta)$

Division ÷ : $(\alpha_2, \alpha_3, \alpha, \beta) \div (b_2, b_3, \gamma, \delta)$

$$\cong (\frac{a_2}{b_2}, \frac{a_3}{b_3}, \frac{a_2\gamma + b_2\alpha}{n^2}, \frac{a_2\delta + b_2\beta}{n^2}), \text{if}(m, n > 0) \quad (11)$$

1.1 Defuzzification process

Defuzzification is the process of producing a quantifiable result in fuzzy logic. Defuzzification problems emerge from the application of fuzzy control to industrial processes (Zhao and Govind, 1991). Fuzzy numbers defuzzification is an important procedure for decision making in a fuzzy environment. The centre of area defuzzification technique is used here. This technique was developed by (Sugeno, 1999). This is the most commonly used technique and is accurate. This method can be expressed as:

$$X^* = \frac{\int \mu_i(x) x dx}{\int \mu_i(x)} \quad (12)$$

where X^* is the defuzzified output, $\mu_i(\chi)$ is the aggregated membership function and χ is the output variable. The above formula can be shown as follows for triangular and trapezoidal fuzzy numbers. Defuzzification of fuzzy number $\tilde{A} = (\alpha_1, \alpha_2, \alpha_3)$ is:

$$X^* = \frac{\int_{a_1}^{a_2} \frac{x-a}{a_2-a_1} x dx + \int_{a_2}^{a_3} \frac{a_3-x}{a_3-a_2} x dx}{\int_{a_1}^{a_2} \frac{x-a_1}{a_2-a_1} dx + \int_{a_2}^{a_3} \frac{a_3-x}{a_3-a_2} dx} = \tfrac{1}{3}(\alpha_1+\alpha_2+\alpha_3) \quad (13)$$

Defuzzification of trapezoidal fuzzy number $\tilde{A} = (\alpha_1, \alpha_2, \alpha_3, \alpha_4)$ can be obtained by Equation 14.

$$X^* = \frac{\int_{a_1}^{a_2} \frac{x-a}{a_2-a_1} x dx + \int_{a_2}^{a_3} x dx + \int_{a_3}^{a_4} \frac{a_4-x}{a_4-a_3} x dx}{\int_{a_1}^{a_2} \frac{x-a_1}{a_2-a_1} dx + \int_{a_2}^{a_3} x dx + \int_{a_3}^{a_4} \frac{a_4-x}{a_4-a_3} dx} \quad (14)$$

$$= \tfrac{1}{3} \frac{(a_4+a_3)^2 - a_4 a_3 - (a_1+a_2)^2 + a_1 a_2}{(a_4+a_3-a_2-a_1)}$$

2. Fuzzy event tree

In conventional event tree analysis, the branch probabilities have been treated as exact values. As already mentioned, however, for many top events questions of accident progression event trees regarding to phenomena encountered during severe accidents, it is often difficult to assign exact branch probabilities or parameters from the current state of knowledge. To illustrate how the fuzzy set theory can be applied to accident progression event trees with imprecise and uncertain branch probabilities; an accident progression event tree is shown Fig. 1.

A_1 and A_2 are the two questions of accident progression event tree, and each question assumed to have only two branches (success or failure/occurrence or non-occurrence of phenomena) for simplicity in presentation. When available data and information for these events are rare, then expert opinion often becomes a major means for quantifying the branch probabilities (Kenarangui, 1991), . In this case, their probabilities might be imprecise and uncertain due mainly to the judgmental uncertainty or subjective bias of the expert. Therefore, it is not possible to assign unique numerical probability values to the branches of the top events. To overcome this difficulty, the concept of fuzzy possibility by using expert judgments can be used instead of a unique value of probability in the analysis of the event tree. A stepwise description of Fuzzy Event Tree Analysis (FETA) algorithm is shown in the following:

1.Constructing event tree logic diagram for an initiating event identified by using the set of possible failure and success states.

2.Identifying top events with vague characteristics, and conduct the linguistic value to assess them.

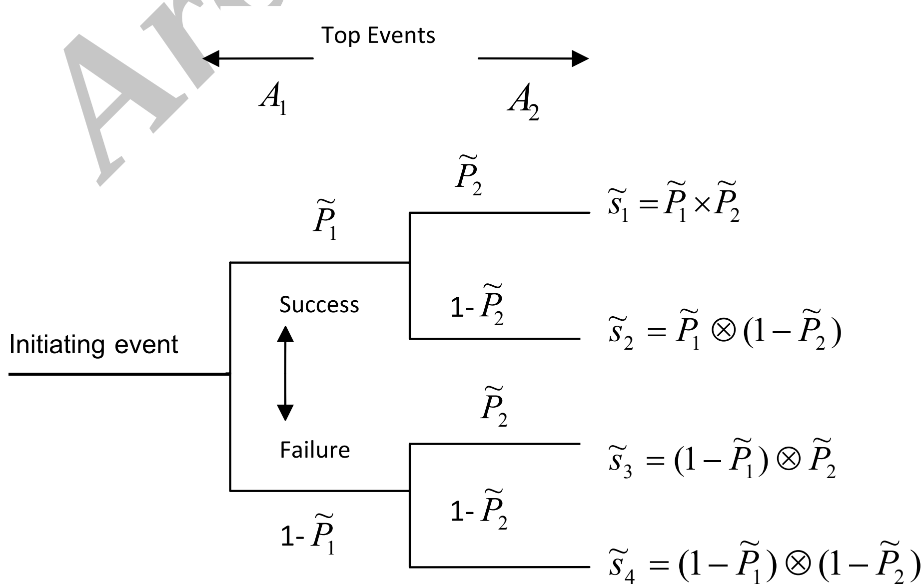


Fig. 1: Sample of an event tree

3.Transform linguistic value into corresponding fuzzy numbers and aggregate experts' opinion into FPS.
4.Convert the probability of known top events and FPS of vague top events into the form of FP.
5.Calculating all tree paths as shown in the Fig. 2.
6.Defuzzification of event tree consequences, analyze and interpret the result.
In consequence modelling, lack of data is the biggest issue. Therefore, the result of traditional ETA model has high level of uncertainty. In order to solve this issue, FETA is employed. FETA approach provides an opportunity to model the consequence of different accident scenarios and also can handle subjective and objective data simultaneously. By employing FETA, it is possible to reduce the uncertainty associated with the traditional analysis and the proposed model can be applied in any consequence modelling.

3. Applying the six - procedure of FETA

Step 1: Constructing event tree logic diagram by using success and failure rate. There are many different types of materials that can be transported by pipelines, and when a failure occurs and the product is released, not all materials will behave equally. The total mass of the release and its rate of release are probably the most important parameters that influence the hazard zone associated with release. A release term will normally vary with time and function of hole size and location, containment conditions, system inventory, and external conditions. If a mixture is involved, the composition of the release may also vary with time. It is very important to establish the initial release rate (over the first 10 seconds or so) for releases of high pressure gases or liquefied gases from pipelines and vessel (JP Kenny Ltd, 2005), because very often it is the initial release rates which control the maximum extent of the hazard zone. Releases and their subsequent dispersion can be categorised according to their timescale:
• Instantaneous- Very short timescale (usually a few seconds). Release follows large scale catastrophic failure or explosion.
• Transient- Release rate varies over a larger period (usually minutes or tens of minutes). For example, a large pipeline failure will result in a decaying release rate as the pipeline depressurises.
• Continuous- Release rate remains constant, or nearly so, over several tens of minutes, or over hours. A small to medium pipework rupture would give this type of release.
Depending upon the characteristics of release, the product may also be more likely to ignite and cause further damage. In general, gas liens and highly flammable fuel lines are considered high impact, meanwhile oil and multiphase pipeline having a high liquid to gas ratio (>2:1) are considered to be in the moderate impact category (Bea & Botand, 1999). The low impact rating is reserved for pipelines that carry water. If pipelines carry very hazardous materials like hydrogen sulphide gas, which is very toxic, consideration must be given to the impact of such a highly toxic gas. Oil on the other hand will not be so toxic to humans, but if it is in the ocean, a lot of marine life may be affected a negative manner. For the sake of simplicity most materials carried by pipelines, especially from offshore, will have hazard rating that brings about a moderate to high impact upon release (Bea and Botand, 1999). For example gas pipelines are considered high impact on land and offshore, but oil pipelines can be classified as having a moderate to high impact depending on weather the shoreline is sensitive or not. For example, failure of many offshore pipelines can seriously impact the shoreline and animals living in the water. On land however, the same failure will only have a moderate impact, depending on the viscosity of the fluid and permeability of the soil. Consequence estimation can be accomplished by (CCPS, 1992):
• Comparison to the past incidents,
• Expert judgement, or
• Using mathematical models (consequence modelling), which can be at various levels of detail and sophistication.
Consequence modelling generally involves three distinct steps (EPA, 1996):
1) Estimation of source term (source term modelling), i.e., how much material in what form (gas, liquid, two-phase) is being released from containment as a function of time, and development of the release scenarios or possible hazard outcomes (toxic cloud, fire, explosion, etc)
2) Estimation of hazard level (hazard modelling) as a function of time and at selected receptor locations, i.e., estimation of:
• Ambient concentration for a toxic or flammable gas release (for modelling the effects of a toxic clouds or flash fire).
• Thermal radiation flux for fires (for a jet fire, pool fire, or fire ball).
• Over pressure for explosions (for a confined explosion, Boiling Liquid Expanding Vapour Explosion (BLEVE), or Vapour Cloud Explosion (VCE)).
By using consequence modelling pipeline failure event tree can be constructed. The Fig. 2 represents the pipeline failure event tree.
Step 2: Identifying the known top events and vague top events. The Fig. 3 represents six different top events

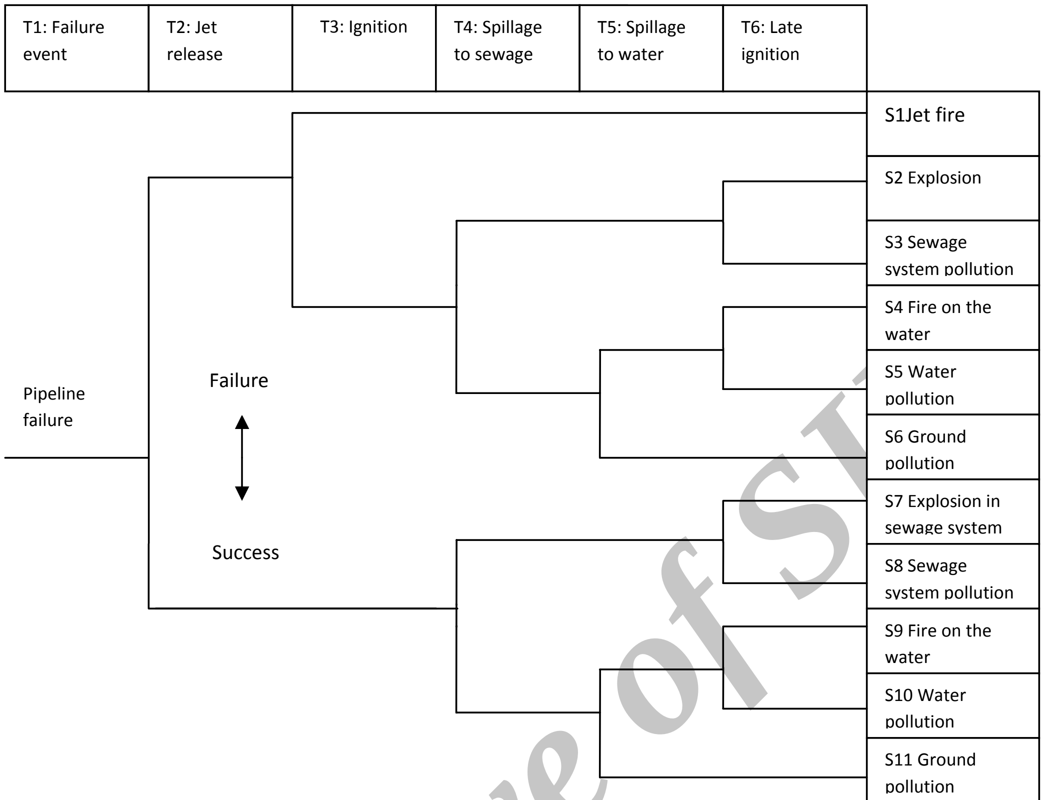


Fig. 2: Event tree analysis of pipeline failure

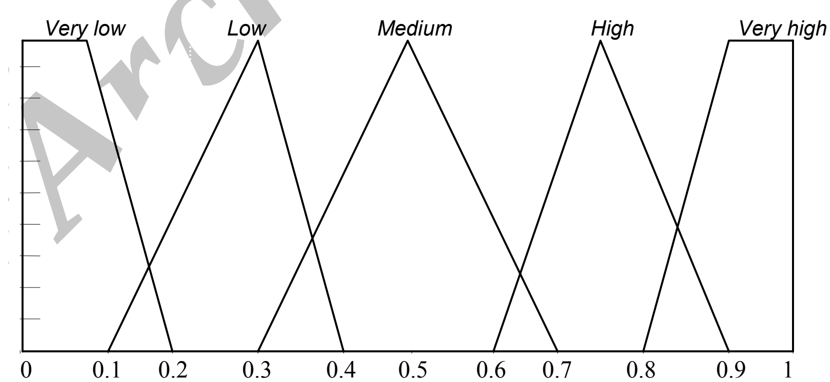


Fig. 3: Chens conversion scale 6

($T_1, T_2,..., T_6$) associated with pipeline failure event tree. There are not any data available (Vague) for four of the top events (T_2, T_4, T_5, T_6). It is often difficult to estimate the precise failure probability of the top events due to insufficient data and vague characteristics of the top events. Therefore, the linguistics value can be used for assessing the vague top events. As noted, the typical estimate of humans working memory capacity it is seven plus-minus two chunks, which means the suitable number for comparisons for human being to judge at a time is between 5 to 9 (Miler, 1956).Therefore,

Chens conversion scale 6 (Table 1) which contains six different linguistic terms is used for assessing the vague events. The Fig. 2. represents the Chens conversion scale6.
Pipeline failure is demonstrated as T_1 in the Fig. 8.The failure rate of the top event T_1 is obtained from fault tree section. This failure rate is FP numbers. As noted, in the proposed event tree there are not any data available for four of the top events (T_2, T_4, T_5, T_6), these top events are treated as vague events. Vague events can be assessed by using fuzzy set theory. The results of the assessment are FPS numbers. FPS numbers can be converted into FP numbers by using the Equation 15.
Onsiawa (1998) has proposed a function which can be used for converting fuzzy failure possibility to fuzzy failure probability. This function is derived by addressing some properties such as the proportionality of human sensation to the logarithmic value of a physical quantity. The fuzzy probability rate can be obtained from fuzzy possibility rate as follows (Onsiawa, 1998; Onsiawa and Nishiwaki, 1988; Onsiawa, 1988; Onsiawa, 1990; Onsiawa, 1996; Lin and Wang, 1998): FP=Fuzzy Probability, FPS=Fuzzy Possibility

$$FP = \begin{cases} \frac{1}{10^k}, FPS \neq 0 \\ 0, FPS = 0 \end{cases}, \quad K = \left[\left(\frac{1-FPS}{FPS}\right)\right]^{\frac{1}{3}} \times 2.301 \tag{15}$$

There is top event with known failure probability (T_3), this top event can be transformed into the FP numbers by using guide line Table 1.
Step 3: Transform linguistic value into corresponding fuzzy numbers and aggregate experts' opinion into FPS by using Equation (16). There are many methods available to aggregate the fuzzy numbers; an appealing approach is linear opinion pool (Clemen and Winkler, 1999).

$$M_i = \sum_{i=1}^{m} W_j A_{ij}, \; j = 1,2,\ldots, n \tag{16}$$

Table 1: Guide line for lower bound and upper bound of failure rate (Swain and Guttmann, 1980; Liang and Wang, 1993; Cheong and Lang, 2004)

Failure rate	Lower Bound	Upper Bound
0.01<Failure rate	Failure rate ÷ 5	Failure rate × 2
0.001<Failure rate<0.01	Failure rate ÷ 3	Failure rate × 3
0.001>Failure rate	Failure rate ÷ 10	Failure rate × 10

Table 2: Fuzzy numbers of conversion scale 6

Linguistic terms	Fuzzy numbers
Very Low (VL)	(0,0,0.1,0.2)
Low (L)	(0.1,0.23,0.25,0.4)
Medium (M)	(0.3,0.5,0.5,0.7)
High (H)	(0.6,0.75,0.75,0.9)
Very High (VH)	(0.8,0.9,1,1)

Table 3: FPSs and FPs of vague event of pipeline failure event tree

FPSs	FPs
T_2= (0.18,0.34,0.34,0.51)	T_2= (1.53E-4,1.3E-3,1.3E-3,5.3E-3)
T_4= (0.1,0.185,0.23,0.37)	T_4= (1.63E-5,1.53E-4,3.6E-4,1.78E-3)
T_5= (0.53,0.7,0.72,0.85)	T_5= (6.15E-5,1.84E-2,2.1E-2,5.1E-2)
T_6= (0.12,0.22,0.26,0.41)	T_6= (3.38E-5,3.13E-4,5.19E-4,2.52E-3)

Table 2 demonstrates all linguistic terms of conversion scale 6 into the form trapezoidal fuzzy numbers.

Failure rate $T_2 = (W_1 + W_2 + W_3 + W_7 + W_9 + W_{10}) \times (L) + (W_4 + W_5 + W_6 + W_8) \times (M) = (0.18, 0.34, 0.34, 0.51)$, and Success rate = $\tilde{1}$ - failure rate.

failure rate $T_4 = (W_3 + W_6 + W_7 + W_8 + W_{10}) \times (VL) + (W_2 + W_4 + W_5) \times (L) + (W_1 + W_9) \times (M) = (0.1, 0.185, 0.23, 0.37)$.

failure rate $T_5 = (W_3 + W_5 + W_8 + W_{10}) \times (VL) + (W_1 + W_2 + W_6 + W_7) \times (H) + (W_4 + W_9) \times (VH) = (0.53, 0.7, 0.72, 0.85)$.

failure rate $T_6 = (W_1 + W_5 + W_6 + W_{10}) \times (VL) + (W_2 + W_8 + W_9) \times (L) + (W_3 + W_4 + W_5) \times (M) = (0.12, 0.22, 0.26, 0.41)$.

Step 4: Converting the probability of known top events and FPS of vague top events into the form of FP. The Table 3 represents the FPSs and FPs vague events. The probability of known events can converted into FP by using guideline Table 5. In the event tree of pipeline failure just T_3 has known probability of failure. T_3 has known failure probability. The probability of failure of ignition is 9.25×10^{-4}. The ignition (T_3) FP can be represented as follows: FP of T_3 = (9.25×10^{-5} , 9.25×10^{-4} , 9.25×10^{-4} , 9.25×10^{-3}).

Step5: Calculating all tree paths as shown in the Fig. 1 Calculations of all three paths of proposed event tree (Fig. 2) are represented in Table 4.

Step 6: Defuzzification of event tree consequences, analyze and interpret the result. The defuzzification method for trapezoidal fuzzy numbers introduced in Equation (18). Since the value of fuzzy outcome

Table 4: All tree paths calculations

$S1 = (3E-10, 8.4E-8, 9.6E-8, 1E-5)$	$S7 = (1.84E-11, 3.33E-9, 6.9E-9, 1.21E-6)$
$S2 = (2.4E-15, 4.3E-12, 8.9E-12, 6.3E-9)$	$S8 = (3.99E-7, 107E-5, 1.24E-5, 3.6E-4)$
$S3 = (5.28E-11, 1.41E-8, 1.62E-8, 1.9E-6)$	$S9 = (7.3E-9, 3.9E-7, 1.31E-6, 3.43E-5)$
$S4 = (9.6E-13, 5.18E-10, 1.71E-9, 1.78E-6)$	$S10 = (1.58E-4, 1.28E-3, 2.39E-3, 1E-2)$
$S5 = (2.09E-8, 1.67E-6, 3.1E-6, 5.58E-5)$	$S11 = (2.3E-2, 6.7E-2, 7.8E-2, 2.05E-1)$
$S6 = (3.12E-6, 9.08E-5, 1E-4, 1E-3)$	$\sum_{i=1}^{11} S_i = (0.025, 0.07, 0.08, 0.207)$

Table 5: The α - cut interval of each sequences, representative (defuzzified) value and rank FETA, and α =1 of occurrence rate of each sequence

Sequence	α - cut interval	Occurrence rate α =1	Fuzzy numbers	Defuzzified value
S1	(8.37E-8 α +3E-10,1E-5-9.9E-6 α)	9E-8 (7)	(3E-10,8.4E-8,9.6E-8,1E-5)	2.54E6 (7)
S2	(4.3E-12 α+2E-15,6.3E-9-6.29E-9 α)	1.32E-11(11)	(2.4E-15,4.3E-12,8.9E-12,6.3E-9)	1.57-9 (11)
S3	(1.4E- α+85.28E-11,1.9E-6-1.8E-6 α)	1.51E-8 (9)	(5.28E-11,1.41E-8,1.62E-8,1.9E-6)	4.82-7 (8)
S4	(5.17E-10 α+9.6E-13,1.78E-7-1.76E-7 α)	1.11E-9 (10)	(9.6E-13,5.18E-10,1.71E-9,1.7E-7)	4.5-8 (10)
S5	(1.64E-6 α+2.09E-8,5.58E-5-5.27E-5 α)	2.35E-6 (5)	(2.09E-8,1.67E-6,3.1E-6,5.58E-5)	1.51-5 (5)
S6	(8.76E-5 α+3.12E-6,1E-3-9E-4 α)	5.45E-5 (3)	(3.12E-6,9.08E-5,1E-4,1E-3)	2.78-4 (3)
S7	(3.31E-9 α+1.84E-11,1.216E-6-1.2E-6 α)	5.06E-9 (8)	(1.84E-11,3.33E-9,6.8E-9,1.21E-6)	3.06-7 (9)
S8	(1.03-5 α+3.99E-7,3.6E-4-3.47E-4 α)	1.15E-5 (4)	(3.99E-7,1.07E-5,1.24E-5,3.6E-4)	9.57-5 (4)
S9	(3.9E-7 α+7.3E-9,3.43E-5-3.29E-5 α)	8.54E-7 (6)	(7.3E-9,3.98E-7,1.81E-6,3.43E-5)	9E-6 (6)
S10	(1.12E-3 α+1.58E-4,1E-2-7.61E-3 α)	1.83E-3 (2)	(1.58E-4,1.28E-3,2.39E-3,1E-2)	3.55E-3 (2)
S11	(0.044 α+2.3E-2,2.05E-1-1.27E-1 α)	7.25E-2 (1)	(2.3E-2,6.7E-2,7.8E-2,2.05E-1)	9.3E-2 (1)

indicate the most possible value in the fuzzy quantity, it can be used to compare with defuzzified value of FP. The results are summarized in Table 5.

In Table 5, the ordering ranked by using the representative (defuzzified) value is different from that provided by using (α=1) occurrence rate of each sequence.

The identification of critical component is essential as far as analysis of any system is concerned. In fuzzy methodology, two difference importance measures are introduced (Suresh et al, 1996). (1) Fuzzy Importance Measure (FIM) and (2) Fuzzy Uncertainty Importance Measure (FUIM).

(1)FIM: the evaluation of the contribution of different events is essential to identify the critical components in the system. More attention can be paid to them to reduce the possibility of system failure. As noted, one useful index called fuzzy importance is used in FTA to indicate the importance of a cause by observing the effect of eliminating it (Liang and Wang, 1993; Furuta and Shiraishi, 1984). FIM has the same characteristic and it can be obtained by using the Equation (17).

$$FIM = \widetilde{P}_T - \widetilde{P}_{T_i} = \sum_{\alpha=0.1}^{1} \left| \widetilde{P}^{\alpha}{}_T - \widetilde{P}^{\alpha}{}_{T_i} \right| = \tag{17}$$

$$\sum_{\alpha=0.1}^{1} \left| \widetilde{P}^{\alpha}{}_T - \widetilde{P}^{\alpha}{}_{T_i} \right| = \sum_{\alpha=0.1}^{1} [\left| \widetilde{P}^{L}{}_T - \widetilde{P}^{L}{}_{T_i} \right| + \left| \widetilde{P}^{R}{}_T - \widetilde{P}^{R}{}_{T_i} \right|]_{\alpha}$$

$\widetilde{P}_T^{\alpha} = [\, \widetilde{P}_T^{L}, \widetilde{P}_T^{R}]$: α -cut of total consequences,

$\widetilde{P}_{Ti}^{\alpha} = [\, \widetilde{P}_{Ti}^{L}, \widetilde{P}_{Ti}^{R}]$: α -cut of total consequences when top event is eliminated.

FIM of each top event is shown in Table 6. FIM can help the analyst to find out the critical event in the system for reducing the occurrence of severe accidents.

(2) FUIM: As noted, FIM can be used to identify the critical events, However, it is also important to identify which event contributes the most uncertainties to the fuzzy outcomes. FUIM can be used for identifying events which contribute the maximum uncertainty to the uncertainty of the system failure consequences. The FUIM can be defined as:

$$FUIM = \widetilde{P}_T - \widetilde{P}_{T_i} = \sum_{\alpha=0.1}^{1} \left| \widetilde{P}^{\alpha}{}_T - \widetilde{P}^{\alpha}{}_{T_i} \right| = \tag{18}$$

$$\sum_{\alpha=0.1}^{1} [\left| \widetilde{P}^{L}{}_T - \widetilde{P}^{L}{}_{T_i} \right| + \left| \widetilde{P}^{R}{}_T - \widetilde{P}^{R}{}_{T_i} \right|]_{\alpha}$$

$\widetilde{P}_T^{\alpha} = [\, \widetilde{P}_T^{L}, \widetilde{P}_T^{R}]$: α -cut of total consequences,

$\widetilde{P}_T^{\alpha} = [\, \widetilde{P}_T^{L}, \widetilde{P}_T^{R}]$: α -cut of total consequences when the occurrence rate of top event is a crisp value.

FUIM can provide the analyst useful information on the design of data gathering strategies that concentrate on the reduction of total uncertainty (Suresh et al, 1996). As noted, FIM can help the analyst to find out the critical top event for reducing the occurrence of severe accident. Table 6 provided the FIM of different top events. T_5 (Late ignition) is the critical top event in the proposed fault tree. Using spearman rank correlation coefficient to compare these two ranks, ranking correlation coefficient can be obtained by Equation (17). Ranking correlation coefficient for Table 6 is r_s

Table 6: Interpreting and ranking the events

Top event	FIM	Ranking	FUIM	Ranking
T_1: Jet release	0.0624	(2)	0.0581	(2)
T_2 : Ignition	0.0597	(3)	0.0623	(1)
T_3 : Spillage to sewage	0.0557	(4)	0.055	(4)
T_4 : Spillage to water	0.0014	(5)	0.0132	(5)
T_5: Late ignition	0.0638	(1)	0.0569	(3)

=0.7. There is slight difference in ranking, this slight difference in ordering maybe mainly due to inherent differences of these two assessment approaches. The defuzzification method introduced in this study considers the uncertainty and vagueness of fuzzy outcomes that are propagated from related events, but α =1 just ranks these outcomes by consideration the highest possible occurrence rate of each sequence. This difference also shows that without considering the uncertainties and vagueness associated with the outcomes, the information about the real state of complex system will not be revealed sufficiently. Therefore, the result of traditional ETA might lead to misunderstanding and wrong decisions without considering the uncertainty associated with outcomes, in order to overcome this advantage fuzzy set theory is employed.

$$r_s = 1 - \frac{6\sum_{i=1}^{N} D^2{}_i}{N(N^2-1)} \qquad (19)$$

D refers to the difference between a subject ranks on the two variables, and N is the number of subjects.

CONCLUSION

From the result of the study, the following conclusions are drawn:

1.A fuzzy methodology for event tree evaluation seems to be an alternative solution to overcome the weak points of the conventional approach: insufficient information concerning the relative frequencies of events.
2. By using linguistic variables, it is also possible to handle the ambiguities involved in the expression of the occurrence of a top event. In addition, the state of each event can be described in more flexible form, by using the concept of fuzzy set.
3. Instead of using the failure possibility, FP is used to characterize the failure occurrence of the system events. It can efficiently express the vagueness of the nature system phenomena and insufficient information. Further, regardless of the complexity of the system, it is also possible to identify which event influence system failure probability the most.
4. After getting the evaluation of all types of the events, the proposed FETA algorithm provides a simple and effective procedure to integrate those events into whole event tree analysis.
5.Without considering the vagueness associated with fuzzy outcomes, the information about the real state of the complex system will not be revealed sufficiently and might lead to wrong decisions.
6. FIM assists the analyst to identify the critical event in the system for reducing the occurrence rate of severe accidents by eliminating the occurrence rate of any top event.
7. FUIM can estimate the level of uncertainty an event contributes to the final consequences. The information about those events should be gathered to reduce the total uncertainty.

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