



## **RELIABILITY OF RISK ASSESSMENT IN PETROCHEMICAL INDUSTRIES**

**<sup>1</sup>Rachid Ouache, <sup>2</sup>Ali A.J Adham**

Faculty of Industrial Management, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300  
Kuantan, Pahang

### **ABSTRACT**

Quantitative Risk Assessment is one of the approaches to assess risks. A fuzzy set is a new mathematical tool to model inaccuracy and uncertainty. In this research paper, an integrate model has proposed to solve problem of uncertainty of initiative events and their consequences. Hazard and operability study, Bow-tie analysis, and layer of protection analysis are methods proposed together as the first step in the model for risk analysis. Reliability-fuzzy is the second step to deal with uncertainty, and simulation is the third step for more accurate of results. From the results realized we can judge that the integration between classical methods, fuzzy approach and simulation is greatest model for more reliability of quantitative risk assessment.

**Keywords:** Reliability, Quantitative Risk Assessment, Hazard and Operability Study, Bow-tie Analysis, Layer Of Protection Analysis, Simulation and Modelling

### **INTRODUCTION**

The importance of risk assessment has increased significantly for industrial company especially in petrochemical industry, and this care have occurred after major accident witnessed in last decades in different area which cause death of thousands of workers, loss of property and negative impact on environment. The increasing complexity of engineering system has imposed substantial uncertainties and imprecise associated with data in risk assessment problems. Reliability of system is the ability to operate under designated operating conditions for a designated period of time or number of cycles through a probability. The Improve of reliability for prolonging the life of the item based on two steps essential, on the one hand, study reliability issues and on the other hand, estimate and reduce the failure rate Quantitative Risk Analysis (QRA) for objective to estimate the outcome event probability of an event tree uses crisp probabilities of events to estimate the outcome event probability or

frequency (Ferdous, 2006; Nieto-Morote & F. Ruz-Vila, 2011). In comparison, qualitative risk analysis identifies the possible outcome of initiating an event. The classifications of uncertainty, aleatory and epistemic uncertainties are the major classes (Adam, Markowski, M. Sam Mannan, 2010; Thalles Vitelli Garcez, Adiel Teixeira de Almeida, 2014). QRA in industry has been used to analyse hazards; however, despite the widespread use, qualitative methods suffer from a number of limitations. The resultant uncertainty combined with the natural or statistical variability within the often scarce information complicates scenario predictions and comparisons (Ferdous, 2006; Adam, Markowski., 2007; Refaul Ferdous, Faisal Khan, Rehan Sadiq, Paul Amyotte, and Brian Veitch, 2011; Adam, Markowski, Sam Mannan, Agata Kotynia, Henryk Pawlak, 2011).

In this study, a new model for quantitative risk assessment is proposed based on three steps: the first is a hybrid of three methods from three approaches – qualitative, quantitative and semi quantitative – HAZOP, Bow-tie and LOPA; the second uses fuzzy sets with methods mentioned before to deal with the problem of uncertainty of inputs and outputs; and the third is integer simulations using Simulink for the most accurate of results, which facilitates the complexity of calculation.

## **CLASSICAL METHODS**

### **Hazard and operability study (HAZOP)**

Hazard and operability study HAZOP has been widely used in chemical process industries, especially in some complex process plants such as processes, human operations, mass material, many pieces of equipment, a number of instruments, several control systems, safety and environment, etc., interweaved to form a complex process plant. The experts have underscored the following four aspects as benefits of HAZOP: (1) determining whether a given operation or activity has the potential to give rise to a hazardous situation, (2) determining the range of hazardous events that the operation or activity could present, (3) identifying the routes by which each of these hazardous events could be realised, i.e., identifying the potential incident scenarios, (4) providing some prevention suggestions or measures to avoid hazardous events if the safeguards are not enough. However, there are problems facing the application HAZOP: (1) the inheritance instrument of the experiential knowledge (Wang, Chin., K.S., Poon, G.K.K. & Yang, J.B., 2009); (2) the classification of accident causes.

## **Bow-Tie Analysis**

Bow-tie analysis is an integrated probabilistic technique that analyzes accident scenarios in terms of assessing the probability and pathways of occurrences. It is intended to prevent, control and mitigate undesired events through development of a logical relationship between the causes and consequences of an undesired event. This technique, which has become useful and effective for assessing risk where a qualitative approach is not possible or desirable. It provides a representation of the causes of a hazardous scenario event and likely outcomes (Huang, Chen, T. & Wang, M.J.J., 2001b; Xiaomin You, M. ASCE and Fulvio Tonon, M. ASCE, P.E., 2012; Refaul Ferdous, Faisal Khan, Rehan Sadiq, Paul Amyotte, Brian Veitch, 2012). Bow tie analysis is a quantitative risk method, used by Shell Oil company for risk management at the beginning of the 1990s. Bow-tie combines three methods, which are FTA, ETA and LOPA, to follow the process of risks from the causes of initiating events using FTA to consequences using ETA and LOPA for preventing accidents and mitigating the consequences. Bow-tie is performed as a qualitative method to assess the incidents and accidents, as well as a quantitative method, which has been found to be more effective in calculating probabilities of final events consequences (Ericson, 2005; CCPS, 2000; Adam, Markowski, Agata Kotynia, 2011; Eduardo Calixto, 2013).

## **Layer of protection analysis lopa**

LOPA was suggested as one method to determine the integrity level for safety instrumented functions (SIFs): classifying SIF to determine the appropriate safety integrity level (SIL), developing a tool to reduce the number of scenarios of quantitative risk assessment (QRA), identifying “safety critical” equipment and systems, developing a semi-quantitative tool to make consistent risk based judgments within an organisation and facilitating communication, such as SIS, SIF, SIL and IPL, between the hazard and risk analysis community and the process control community (Ossama, Abul-Haggag1, Walied Barakat, 2013; Nouara Ouazraoui, Rachid Nait-Said, Mouloud Bourareche, 2013; Lei Ma, Yongshu Li, Lei Liang, Manchun Li, Liang Cheng, 2013).

For LOPA, the analyst must limit each analysis to a single consequence, paired to a single cause (initiating event). In many applications of LOPA, the goal of the analyst is to identify all cause-consequence pairs that can exceed the organisation’s tolerance for risk (CCPS, 2001).

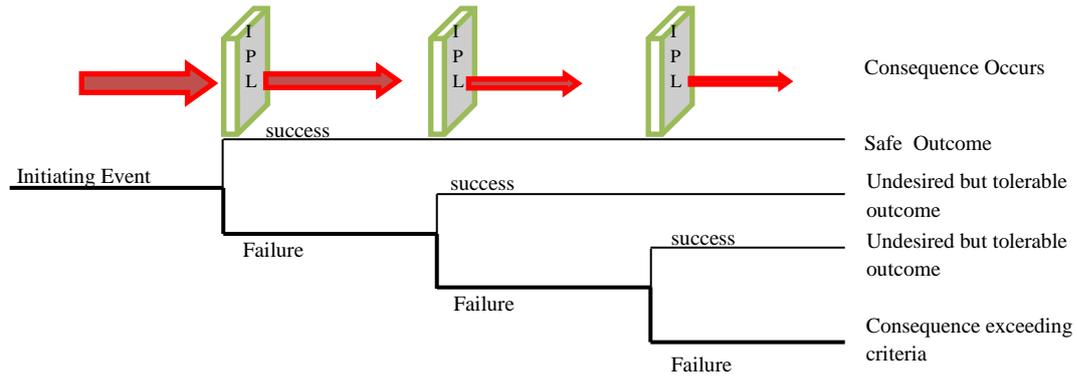


Figure 1: Integration Layer of protection analysis in the Event tree analysis

## QUANTITATIVE CALCULATION OF RISK AND FREQUENCY

The following is the general procedure for calculating the frequency for a release scenario with a specific consequence endpoint.

$$f_i^c = f_i^l \prod_{j=1}^J PFD_{ij} = f_i^l \times PFD_{i1} \times PFD_{i2} \times \dots \times PFD_{ij} \quad (1)$$

$$\text{Where: } f_i^c \times PFD_{pl} = TR \quad (2)$$

And risk reduction factor for reducing the risk to a tolerable level

$$RRF_{pl} \geq \frac{f_i^c}{TR} \quad (3)$$

For objective to reach tolerability of risk, the value of  $\frac{f_i^c}{TR}$  consider as a minimum risk reduction factor (MRRF).

## RELIABILITY AND FUZZY

### PROBIST Reliability

PROBIST reliability is the same as conventional reliability theory. It considers probability assumption and the binary-state assumption. PRO stands for probability and BIST stands for binary states. The reliability of component or the system that is computed using the PROBIST reliability theory is PROBIST component or PROBIST system. In PROBIST system, the component or system failure is based on the probability theory. Also, two deterministic or

crisp states, which means fully operating and fully failed states, are considered and the system will be in one of these two states at any given point in time (Cai, C. Y Wen, & M. L. Zhang, 1991; Cai, C. Y. Wen, and Zhang, M.L., 1993; Cai, 1996).

The PROBIST reliability is often viewed as a fuzzy set. PROBIST reliability can be in the form of linguistic values or most of the time the form of an interval. This reliability can be viewed as a fuzzy number. Most of the ongoing research considers reliable as a fuzzy number in the form of triangular, trapezoidal and normal fuzzy numbers, which are presented in the following section (Huang, 1995).

### PROBIST reliability as a TFN

PROBIST reliability is assumed as a triangular fuzzy number (TFN). The essential part of fuzzy set theory is getting the information or data from the experts, and hence the expert's judgment plays a vital role in the evaluation of reliability. Let the interval value of initial reliability  $R_i$  be  $[l, r]$ . The middle or crisp value  $m$  of this T.F.N is  $\frac{l+r}{2}$  i.e. the T.F.N is symmetric [10]. Let  $n$  be the number of experts. The PROBIST reliability values of the system are obtained from these  $n$  experts based on their judgment. Their expertise is represented by T.F.N:

$$E^{(i)} = (m^{(i)} - d^{(i)}, m^{(i)}, m^{(i)} + d^{(i)}); \quad i=1,2,3,\dots,n \quad (4)$$

We need to arrive at a single T.F.N value of the PROBIST reliability from the expert's judgment. Let the final T.F.N of the PROBIST reliability be  $F=(f-g, f, f+g)$ . Parameters  $f$  and  $g$  are determined using

$$g = \frac{1}{n} \sum_{i=1}^n d^{(i)} \quad (5)$$

$$f = \frac{\min m^{(i)} + \max m^{(i)}}{2}; \quad 1 \leq i \leq n \quad (6)$$

A similar procedure may also be applied for trapezoidal fuzzy numbers, i.e. PROBIST reliability, as the trapezoidal fuzzy number.

### Fuzzy PROBIST series system reliability

The PROBIST series system is shown as below:

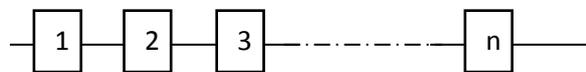


Figure 2: Component of system *en serie*

N= number of components

$R_i$ = reliability of component I in T.F.N. ;  $i= 1,2,\dots,n$

The series system reliability is given by:

$$[R_{SS}] = \prod_{i=1}^n R_i \quad (7)$$

Let  $R_i = [l_i, m_i, r_i]$  be a T.F.N ;  $i = 1,2,\dots,n$

Here, we use the  $\alpha$ -cut method to get the fuzzy PROBIST series reliability.

$$[R_{SS}]_\alpha = \prod_{i=1}^n [R_i]_\alpha = \left\{ \prod_{i=1}^n [l_i + (m_i - l_i)\alpha], \prod_{i=1}^n [r_i + (r_i - m_i)\alpha] \right\}, \forall \alpha \in [0,1] \quad (8)$$

Without using  $\alpha$ -cut method,  $R_{SS}$  can be computed.

$$\text{If } R_i = \{m_i - d_{1i}, m_i, m_i + d_{2i}\} \quad (9)$$

Where  $d_{1i}$  and  $d_{2i}$  are the spreads from  $m_i$  of T.F.N on left and right side respectively for each component  $i$ . If  $d_{1i}$  and  $d_{2i}$  are equal, then T.F.N is a symmetric T.F.N.

$R_{SS}$  is given by:

$$R_{SS} = \{ \prod_{i=1}^n (m_i - d_{1i}), \prod_{i=1}^n m_i, \prod_{i=1}^n (m_i + d_{2i}) \} \dots \dots \dots (10)$$

**Fuzzy PROBIST parallel system reliability**

The PROBIST parallel system consists of n components as shown below:

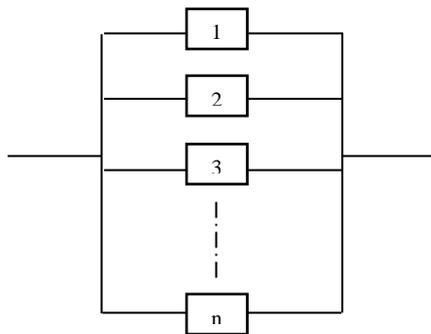


Figure 3: Component of system *en parallel*

A parallel system reliability in this case is

$$R_{PS} = 1 - \prod_{i=1}^n [(1 - R_i)] \quad (11)$$

Again, we consider  $R_i$  as T.F.N. with  $[l_i, m_i, r_i]$  ;  $i=1,2,\dots,n$

Using  $\alpha$ -cut method:

$$R_{PS} = 1 - \prod_{i=1}^n [1 - (R_i)_\alpha] = 1 - \prod_{i=1}^n \{ [1 - (l_i + (m_i - l_i)\alpha)], [1 - (r_i - (r_i - m_i)\alpha)] \} \\ \{ 1 - \prod_{i=1}^n [1 - (l_i + (m_i - l_i)\alpha)], 1 - \prod_{i=1}^n [1 - (r_i - (r_i - m_i)\alpha)] \} \quad \forall \alpha \in [0,1] \quad (12)$$

Without using  $\alpha$ -cut method,  $R_{PS}$  can be computed using the same notations as described in the earlier section as:

$$R_{PS} = \left\{ 1 - \prod_{i=1}^n [1 - (m_i - d_{1i})], 1 - \prod_{i=1}^n [1 - (m_i)], 1 - \prod_{i=1}^n [1 - (m_i + d_{2i})] \right\} \quad (13)$$

Taking a trapezoidal fuzzy number, similar treatment can be given to obtain expressions for fuzzy  $R_{PS}$ .

### Fuzzy Set Theory FS

The fuzzy logic provides an inference structure that enables appropriate human reasoning capabilities. Fuzzy inference system FIS is a non-linear modeling approach that plots the relationship between input and an output using rule of set of fuzzy IF-THEN rules. Zadeh proposed the set membership idea to make suitable decisions when uncertainty occurs. Soft computing is a useful tool for solving problems in many fields (Canos, V. Liern, 2008; Bouchon-Meunier B, Yager R, Zadeh, 1995; Radim Bris, Sava Medonos, ChrisWilkins, Adam Zdráhala, 2013). Fuzzy set theory deals with mathematical model information uncertainties and has been developed and applied in a number of real world applications (Chen, TT. Pham, 2001; Refaul Ferdous, Faisal Khan, Rehan Sadiq, Paul Amyotte, Brian Veitch, 2012; Zadeh, 1965; Nait-Said, F. Zidani, and N. Ouzraoui, 2008; Nait-Said, F. Zidani, N. Ouzraoui, 2009; Wu Wei, Guangxu Cheng, Haijun Hu, Qi Zhou, 2013).

### Fuzzy Numbers

A fuzzy number  $\tilde{A}$  is a subset of real line  $R$ , whose membership function  $\mu_{\tilde{A}}(x)$  can be a continuous mapping from  $R$  into a closed interval  $[0,1]$  (Dubois, D. & Prade, H., 1978; Wang, J. B. Yang, J.B., Xu, D.L. & Chin, K.S, 2006). The membership function of the number  $\tilde{A}$  can be expressed as follows.

$$\mu_{\tilde{A}}(x) = \begin{cases} \mu_{\tilde{A}}^L(x), & a \leq x \leq b \\ 1, & b \leq x \leq c \\ \mu_{\tilde{A}}^R(x), & c \leq x \leq d \\ 0, & \text{otherwise} \end{cases} \quad (14)$$

Where  $\mu_{\tilde{A}}^L: [a,b] \rightarrow [0,1]$  and  $\mu_{\tilde{A}}^R(x): [a,b] \rightarrow [0,1]$ . The former is called the left membership function and the latter is the right membership function (Abbasbandy, T. Hajjari, 2009; Wang, J. B. Yang, J.B., Xu, D.L. & Chin, K.S, 2006). If both  $\mu_{\tilde{A}}^L$  given in Eq.(8) and  $\mu_{\tilde{A}}^R(x)$  given in Eq.(9) are linear as shown in Figure 1, then the fuzzy number  $\tilde{A}$  is a trapezoidal fuzzy number

and usually denoted by  $\tilde{A} = (a, b, c, d)$ . In a special case  $b=c$ ; the trapezoidal fuzzy number into a triangular fuzzy number.

$$\mu_{\tilde{A}}^L(x) = \frac{x-a}{b-a} \quad (15)$$

$$\mu_{\tilde{A}}^R(x) = \frac{d-x}{d-c} \quad (16)$$

### Fuzzy inference system FIS

Fuzzy systems based on transformation of rules of reasoning human beings to mathematic equivalent for simplifying a system designer's work, risk decision makers. The IF-THEN rule statements are used to illustrate the conditional statements that comprise fuzzy logic. Two types of fuzzy inference system can be demonstrated: linguistic (Mamdani Type) and Takagi–Sugeno (TS) fuzzy models. Fuzzy sets provide a means to model the uncertainty associated with vagueness, imprecision and lack of information regarding a problem, a plant, etc. (Dubois, H. Prade, 1980; Zadeh, L.A, 1978).

### APPLICATION ON STORAGE TANK

The storage tank is designed to hold a flammable liquid under slight nitrogen positive pressure under controls pressure (PICA-1) (CCPS, 2000). In addition, the tank is fitted with a relief valve to cope with emergencies. Liquid is fed to the tank from tank trucks. A pump (P-I) supplies the flammable liquid to the process.

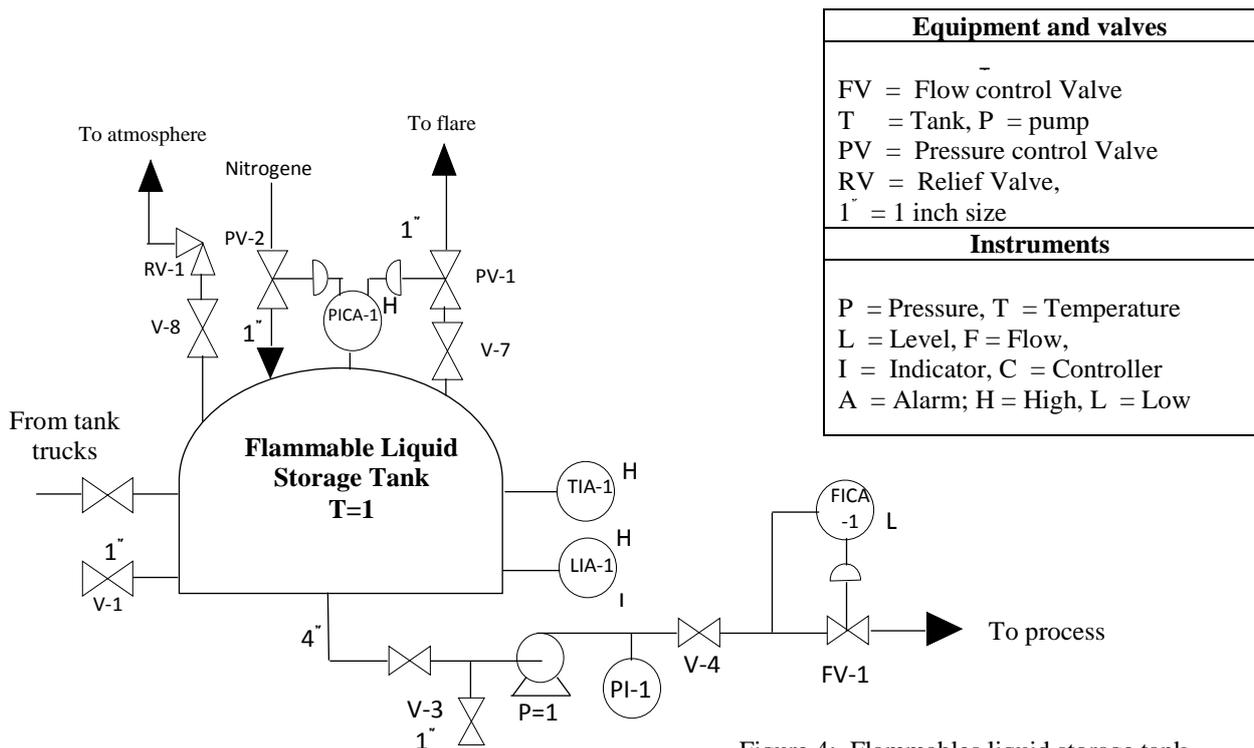
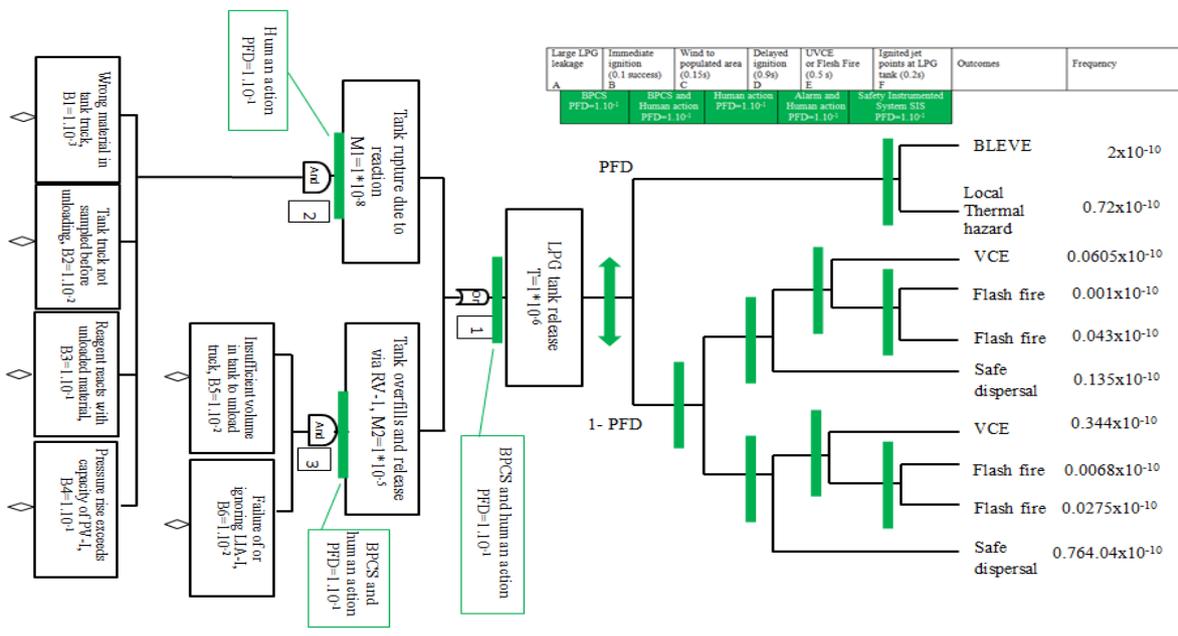


Figure 4: Flammables liquid storage tank

Table 1: Application of HAZOP on system above for one case

Guide word	Deviation	Consequences	Causes	Existing protection	Action items or recommendations
More of	Increase LPG in tank	LPG tank release	-Failure of or ignoring LIA-I -insufficient volume in tank to unload truck -pressure rise exceeds capacity of PV-I	Controls pressure (PICA-I)	Reinforce safety by adding safeguards such as safety instrumented system

Figure 5 represents the integration of bow-tie analysis and layer of protection analysis for objective to get an acceptable case as low as reasonably practicable ALARP.



Integration of simulation using SIMULINK and the fuzzy using Mamdani approach by MATLAB for reliability quantitative risk assessment after application of Bow-tie analysis and Layer of protection analysis. This is summarised in Figure 6.

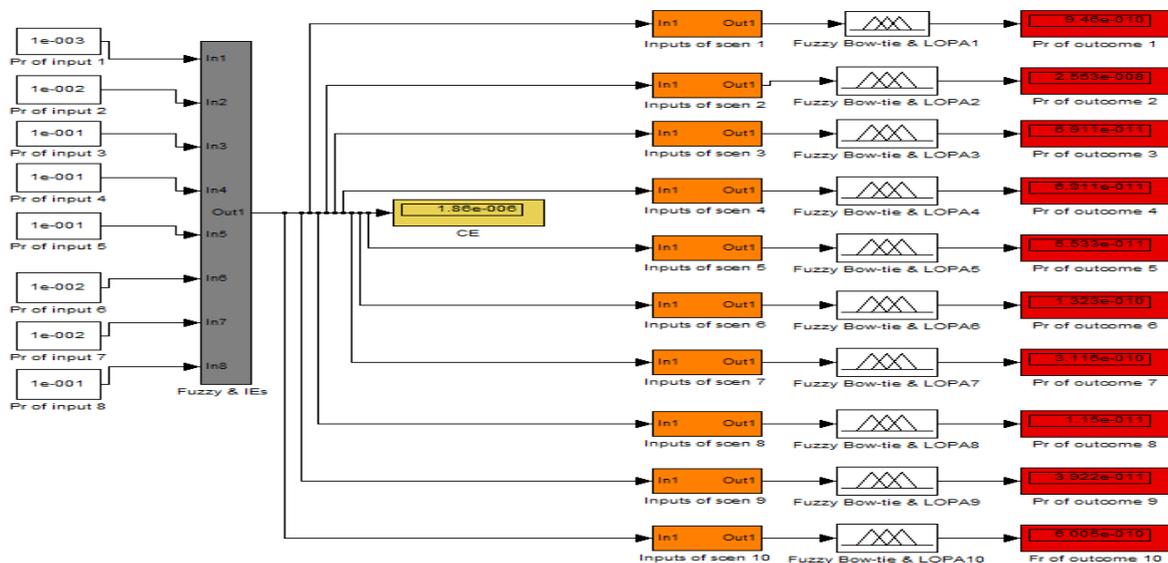
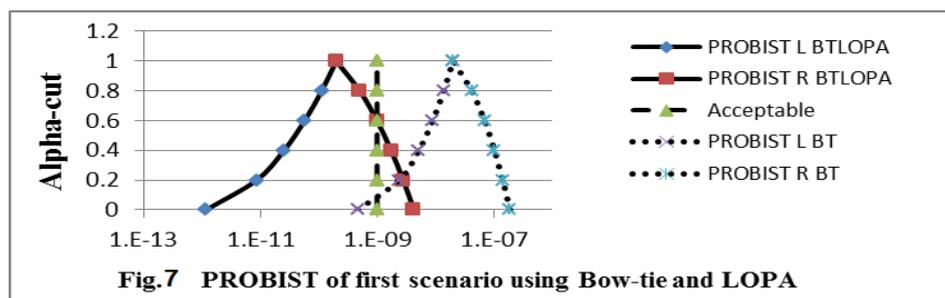


Figure 6: Integration of simulation using (Simulink) and fuzzy approach in risk analysis methods Bow-tie and LOPA

Table 2: Results of PROBIST in Event Tree Analysis (Scenario 1)

Alpha-cut	PROBIST L BTLOPA	PROBIST R BTLOPA	PROBIST L Bowtie	PROBIST R Bowtie
0	1.1721E-12	4.2778E-09	4.6886E-10	1.9012E-07
0.2	8.6370E-12	2.8024E-09	2.3991E-09	1.4298E-07
0.4	2.5499E-11	1.7386E-09	5.2040E-09	1.0288E-07
0.6	5.7573E-11	9.9837E-10	8.9959E-09	6.9331E-08
0.8	1.1248E-10	5.0636E-10	1.3887E-08	4.1848E-08
1	1.9990E-10	1.994E-10	1.9990E-08	1.994E-08



## DISCUSSION

The application of new model for risk assessment has realized objectives as follow: As the first step, hazard and operability study, Bow-tie analysis, and layer of protection analysis, are three methods combined for risk assessment. The results of application mention that it is helpful model for risk analysis. The second step, PROBIST and Mamdani fuzzy is fittest to deal with uncertainty of outcomes. PROBIST assists with defining the range of Mamdani fuzzy is motivated to deal with all possibilities of outcomes and precise value in the range which is defined by PROBIST using centroid of area. The third step, integration of simulations with risk analysis methods, reliability and fuzzy approach. the results are motivate and are helpful: to precise results, facilitate the complexity of calculations and check the results of classical methods.

## CONCLUSION

A new model has proposed to solve problem of risk assessment from three perspectives. For analysis by integrate three methods HAZOP, Bow-tie and LOPA. Integration reliability and fuzzy approach to deal with uncertainty using PROBIST and Mamdani fuzzy. Integration of simulation for more accurate results, facilitates the complexity of calculation and checks the results of classical methods. From all this result, we can judge that integration between classical methods, fuzzy approach and simulation are the best model for reliability quantitative risk assessment.

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