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Research Article

Reliability Quantitative Risk Assessment in Engineering System using Fuzzy Bow-Tie

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Abstract

Quantitative risk assessment (QRA) and reliability are important approaches in modern safety to deal with reliable decision. QRA is the best approach to estimating the initiating events and its probable consequences. However, the weakness of assessment still the main problem faces its advancement. In this study, the Bow-tie analysis based on fault tree analysis and event tree analysis are proposed to solve the problem using fuzzy sets to deal with uncertainty and imprecise of results. The risk in Petroleum Company concerned in this article, where fuzzy sets is an approach used to help analysis methods to precise the values of initiating events and outcomes. The results have gotten are motivate and more precise which help us to deal with the uncertainty of initiating events and consequences.

Keywords: *Quantitative risk analysis, Bow-tie analysis, Fault tree analysis, Event tree analysis, Fuzzy sets, and Reliability.*

1. Introduction

The safety becomes the first factor more important in the world, where suffered in the last decades from risks in different sectors. Reliability in quantitative risk assessment is the best approach used for a management risk, which by its turn the systems developed suffer from lack knowledge and imprecise the results for achieve its objectives (Mohammad**,** 1999; Epstein,2005; Gupta,2007; Ireson,1988; Yang, 2007). Probability models are become widespread in risk quantification and assessment for deal with Lack of experience data, and imprecise data which make it difficult to assess the degree of exposure to certain risk types using only traditional probability models. Sometimes, even with a credible quantitative risk model calibrated to experience data, the cause of the risk and its characteristics may be incompletely understood. Interestingly, while well-accepted and complex quantitative models are available for market, credit and insurance risk, these risks are normally outside the control of business managers (Kaplan**,**1981;Michael, 2012). On the other hand, with appropriate risk identification and risk control in place, operational risk can be significantly mitigated, despite the lack of consensus concerning which quantitative models should be used. Therefore, it may be beneficial to build and implement more appropriate operational risk models using a newer approach such as fuzzy logic.

This study focuses on the application of fuzzy logic and fuzzy set theory, introduced by mathematician Lotfi A. Zadeh in 1965, to risk assessment. Fuzzy logic models are more convenient for incorporating different expert opinions and more adapted to cases with insufficient and imprecise data (Dawson,1994). They provide a framework in which experts' input and experience data can jointly assess the uncertainty and identify major issues (Adam,2010; Hartford,2004). Using approximation and making inferences from ambiguous knowledge and data, fuzzy logic models may be used for modeling risks that are not fully understood. Some operational and emerging risks evolve quickly. Risk managers may not have enough knowledge or data for a full-blown assessment using models based on probability theory (Mariana, 2001; Rasmussen,1975;Refaul,2009).

In this study, Bow-Tie analysis using fuzzy logic proposed as an approach that integrates a fault tree and an event tree analysis to represent causes and consequences of initiating event. Fault Tree Analysis, FTA deductive approach focuses on a top event for calculating the frequency of basic events as well as intermediate events (Vesely,1981; Raman, 2004). From a time progression perspective, the fault tree ends with the top event. Conversely, and Event Tree inductive approach, identifying and evaluating potential consequences, based on the top event for calculating the probability of its consequences (Ferdous, 2006; Eduardo, 2013; Refaul,2011; Xiaomin,2012).

2. Fuzzy Bow-Tie

2.1 Bow-Tie Analysis

The Bow-tie method offers many attributes of the Hazard and Operability (HAZOP) (Philley 2006; Ericson, 2005).

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The Bow-tie method can accommodate multiple outcomes and simultaneous multiple failure events, making it possible to assimilate an accident scenario to a sequence of events and a sequence of barriers that are mitigating these events. Bow-tie Analysis provides a visual representation of the causes of unintended events, likely consequences. Bow-tie Analysis is easily understood by all levels of operations and management (Kenarangui, 1991; Gifford, 2003).

Bow tie analysis is a quantitative risk method, used by shell oil company for risk management at the beginning of 1990, knowing Bow-tie comes to combine three methods together, which includes FTA, ETA and LOPA for follow the process of risks from the causes of initiating events using FTA to consequences using ETA and LOPA for preventing accidents and mitigate the consequences. Bow-tie performed as qualitative method to assess the incidents and accidents, but performed also as quantitative method which has found better as to calculate probabilities of final events consequences (Eduardo, 2013; Philley, 2006).

The Bow-tie diagram is an effective method used in risk assessment, which allow preventing and mitigating the consequences. Bow-tie diagram used to display the results of various types of risk assessments. In this paper Bow-tie analysis using fuzzy logic proposed for more precise the value of the basic events and consequences events. This will help the industry to minimize the level of risk and maximize the level of safety.

The Bowtie approach is based on the swiss cheese model developed by British psychologist James T. Reason in 1990 (Reason, 1997; Haimes, 2004). The Bow-tie has become useful and effective for assess 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. The Bow-tie method, the designated top event output of a Fault Tree is the starting point for an Event Tree as simple example shows in the figure below.

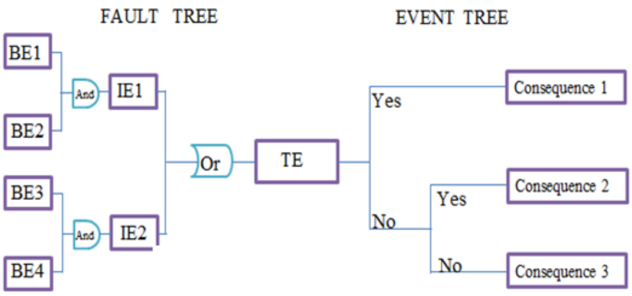

Figure.1 Bow-tie Model simple

2.2 Fuzzy Logic Fl And Fuzzy Set Theory FS

The fuzzy logic provides an inference structure that enables appropriate human reasoning capabilities.

2.1.1 Fuzzy Sets FS: The utility of fuzzy sets lies in their ability to model uncertain or ambiguous data, FS is important to observe that there is an intimate connection between Fuzziness and Complexity. Fuzzy sets provide means to model the uncertainty associated with vagueness, imprecision, and lack of information regarding a problem or a plant, etc (Dubois, 1980, Zadeh, 1978; Hartford,2004).The uncertainty is found to arise from ignorance, from chance and randomness, due to lack of knowledge, from vagueness. (Canos, 2008; R. Nait-Said,2008,2009; Bouchon et al, 1995; Radim Bris, 2013).

2.2.2fuzzy Numbers: The membership function $\mu_{\tilde{A}}(x)$ has the following characteristics (Dubois & Prade 1978). The membership function of the number $\tilde{A}$ can be expressed as follows

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

$$\mu_{\tilde{A}}^{L}(x) = \frac{x-a}{b-a} \quad (2)$$

$$\mu_{\tilde{A}}^{R}(x) = \frac{d-x}{d-c} \quad (3)$$

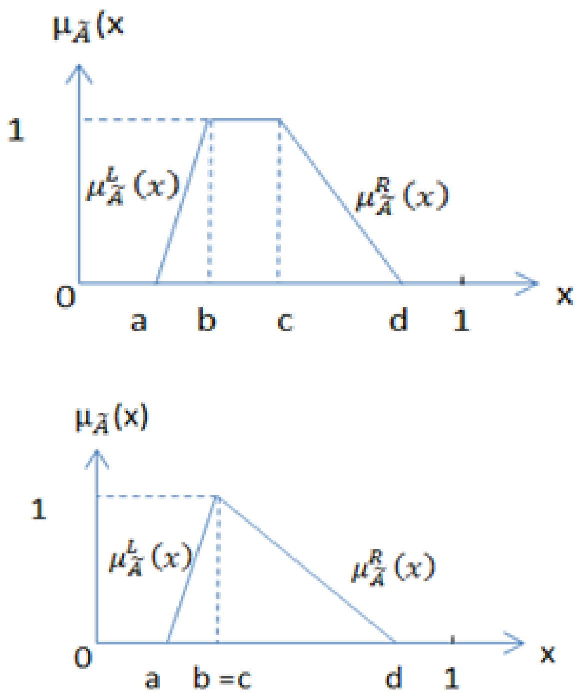

Figure.2 Trapezoidal and triangular fuzzy numbers

2.2.3 Fuzzy inference system FIS: Sugeno method is most commonly used fuzzy inference method (sugeno,1985; Guh, 2008; Wang, 2006, 2009). A typical rule in sugeno fuzzy model has the form, if input 1=x and input 2 =y, then output

$$z = ax+by+c \quad (4)$$

The final output of the system is weighted average of all the rule output which is given as:

$$\text{Final output}=\frac{\sum_{i=1}^{N} w_i z_i}{\sum_{i=1}^{N} w_i} \quad (5)$$

A FIS with five functional block described in Figure.3.

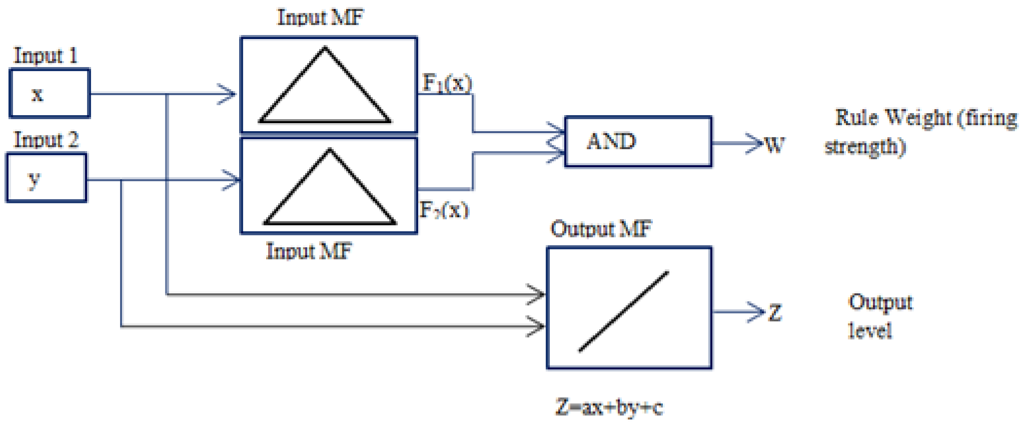

Figure.3 Sugeno rule operates diagram

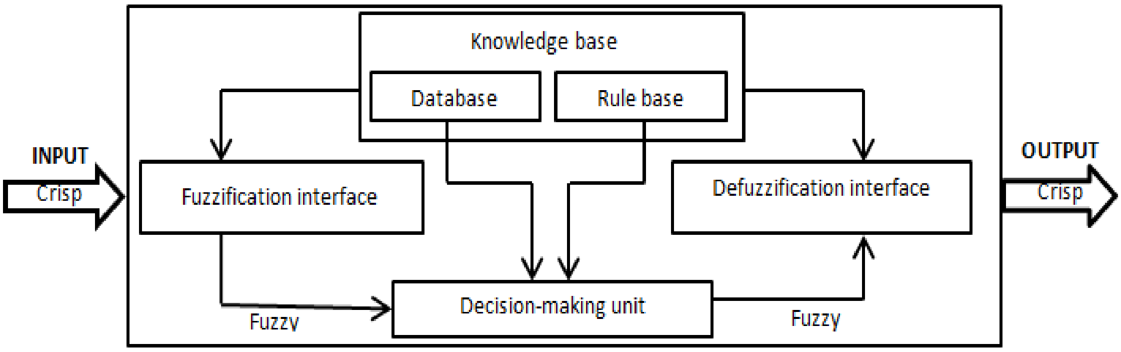

Figure.4 Fuzzy inference system

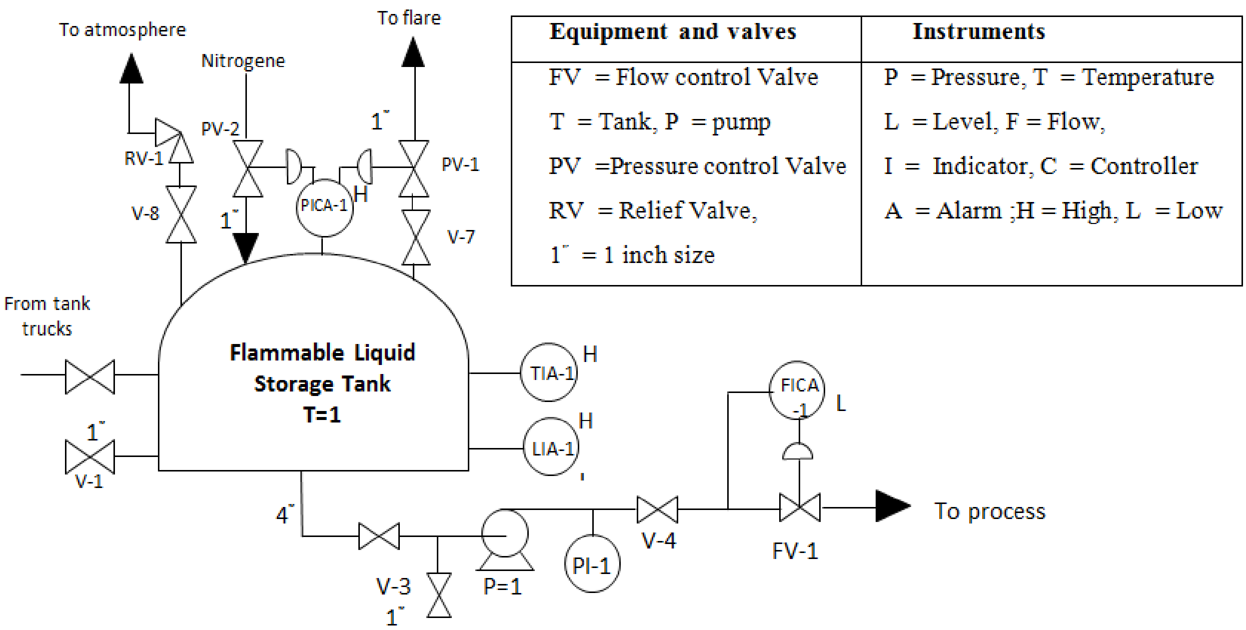

Figure.5 Flammables liquid storage tank.

3. Case Study

The storage tank is designed to hold a flammable liquid under slight nitrogen positive pressure under controls pressure (PICA-I). 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. LPG is a highly flammable gas, whereas the release of LPG may lead to fire and explosion in the presence of an ignition source. The database collects from CCPS (2000). This study focuses on fault and event tree analysis.

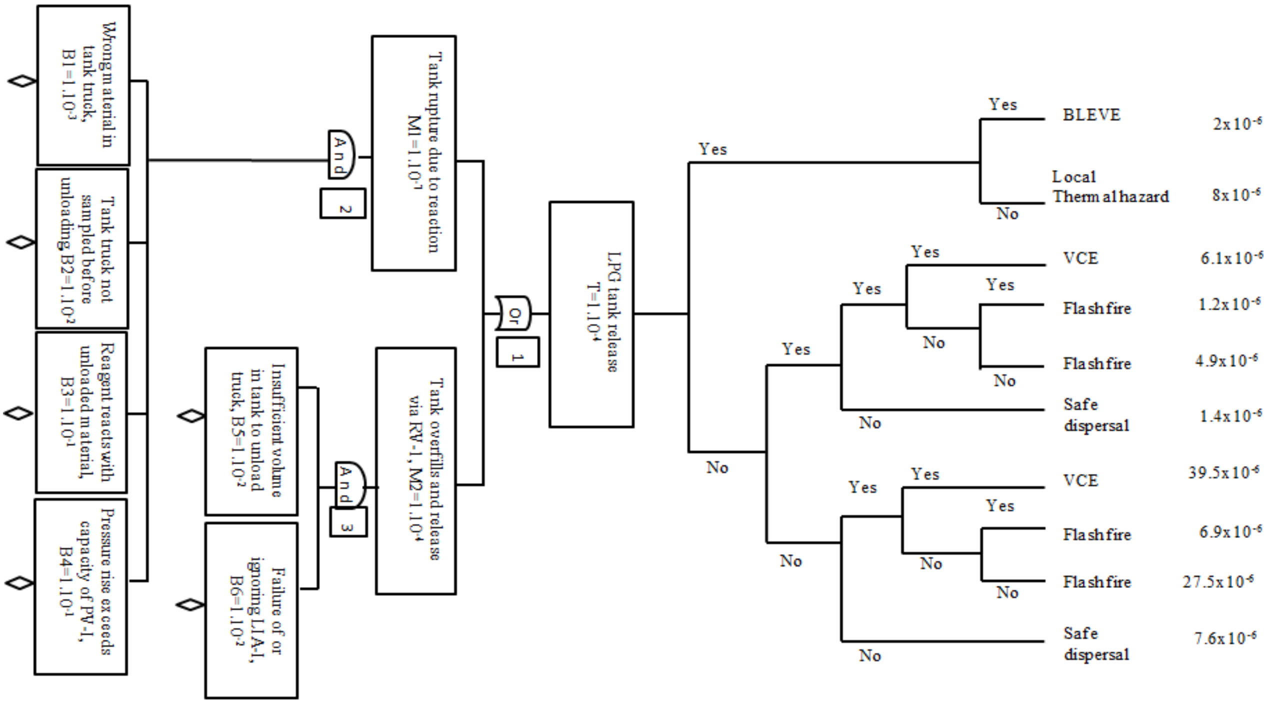

Figure.6 Bow-tie analysis for LPG tank release as top event using classical method

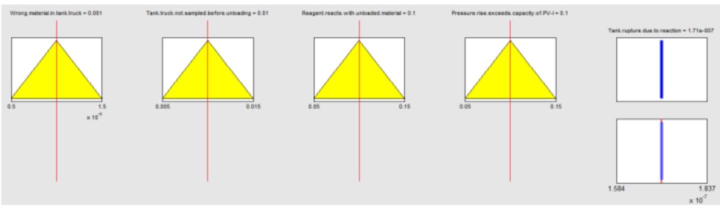

Figure.a Rules inferences process of Tank rupture due to reaction, four inputs with one output

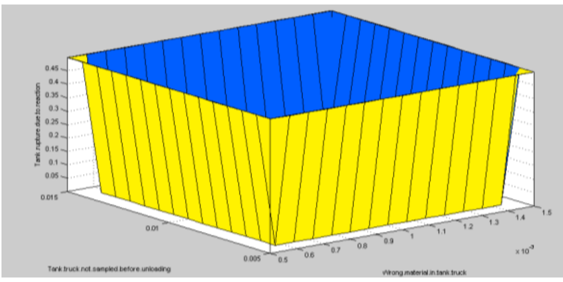

Figure.b Three dimensional diagram Tank rupture due to reaction, Tank truck not sampled before unloading and Wrong material in tank truck

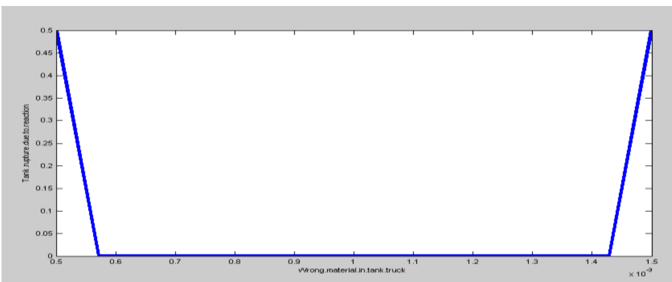

Figure.c Two dimensional diagram, Tank ruptures due to reaction with Wrong material in tank truck

Figure.7 Simulation of inputs and outputs of fuzzy inference using sugeno approach

The Tables.1-2 Show calculates probability using fault and event tree analysis using classical method and fuzzy sets.

Table.1 Tank rupture using Boolean algebras and fuzzy inference methods (Gate.2) by fault tree analysis

Calculate probability using Boolean algebras method									
Wrong material in tank truck		AND	Tank truck not sampled before unloading	AND	Reagent reacts with unloaded material	AND	Pressure rise exceeds capacity of PV-I	THEN	Tank rupture due to reaction
B1=1.10^{-3}			B2=1.10^{-2}		B3=1.10^{-1}		B4=1.10^{-1}		M1=1*10^{-7}
Calculate probability using fuzzy inference method									
IF	B1=1.10^{-3}	AND	B2=1.10^{-2}	AND	B3=1.10^{-1}	AND	B4=1.10^{-1}	THEN	M1=1.71*10^{-7}
	B1=0.504*10^{-3}		B2=0.504*10^{-2}		B3=0.504*10^{-1}		B4=0.504*10^{-1}		M1=1.61*10^{-7}
	B1=1.5*10^{-3}		B2=1.5*10^{-2}		B3=1.5*10^{-1}		B4=1.5*10^{-1}		M1=1.82*10^{-7}

Table.2 Frequency of consequences for large LPG leakage using fuzzy inference methods (scenario.10) by event tree analysis

Calculate frequency of outcome using classical method											
large LPG leakage	AND	Immediate ignition/ NO	AND	Wind to populated area/NO	AND	Delayed ignition/ NO	AND	UVCE or Flash Fire/ /	AND	Ignited jet points at LPG tank/	THEN	Safe dispersal
1*10^{-4}		0.9		0.85		0.1		/		/		7.6*10^{-6}
Calculate frequency of outcome using fuzzy inference method											
1*10^{-4}	AND	0.9	AND	0.85	AND	0.1	AND	/	AND	/	THEN	2.22*10^{-5}

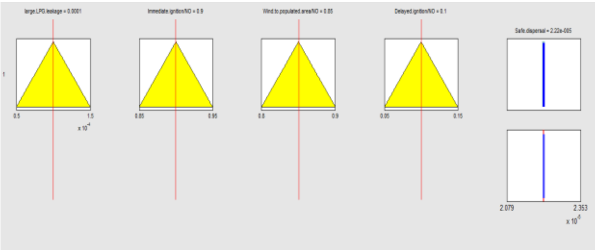

Figure.a Rules inferences process of Safe dispersal, four inputs with one output

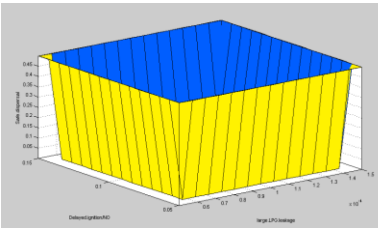

Figure.b Three dimensional diagram, Safe dispersal of leakage without delayed ignition

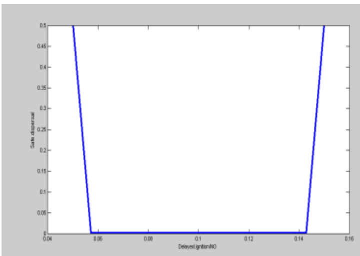

Figure.c Two dimensional diagram shows relationship between delayed ignition and safe disposal

Figure.8 Simulation of inputs and outputs of fuzzy inference using sugeno approach.

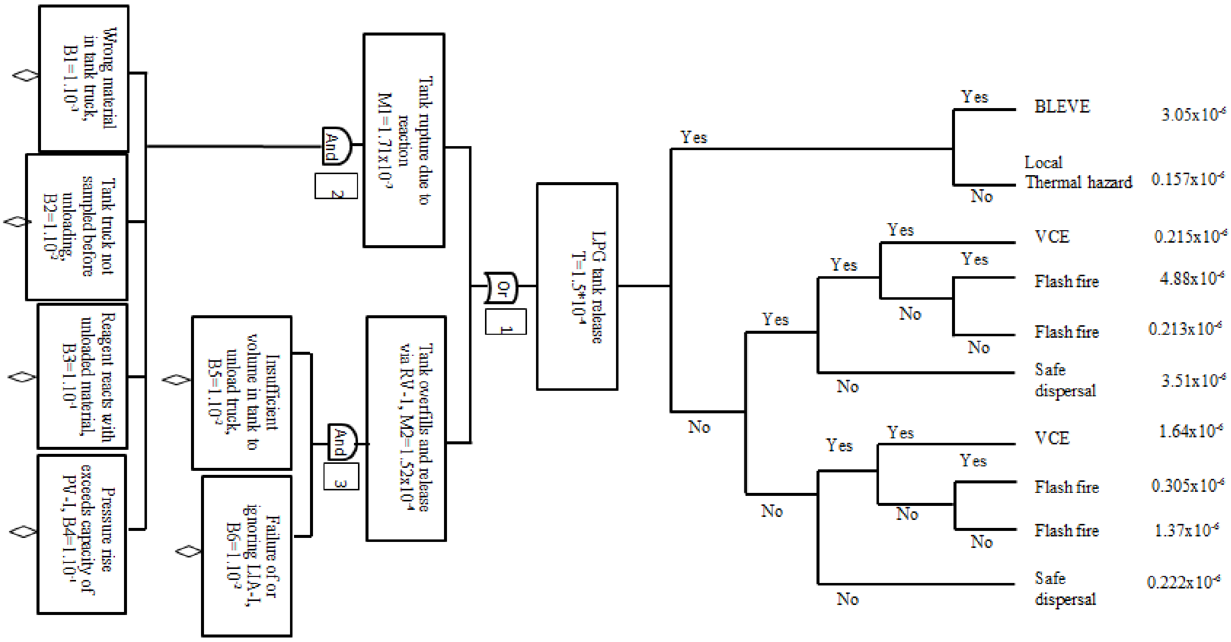

Figure.9 Bow-tie after the results using fuzzy sets for calculate probability of top event and consequences LPG tank release

4. Discussion

The results which have gotten using bow-tie analysis and fuzzy sets is powerful and helpful to precise the values of initiating events and consequences, the figure above shows the results of fuzzy sets on Bow-tie analysis. Probability of consequences clearly illustrates that fuzzy sets has power to deal with uncertainty of initiating events and consequences. The combination between two methods FTA, ETA using Bow-tie and fuzzy sets allow to deal with both deductive and inductive results.

From the figures, Rules inferences illustrate the relationship between the inputs and output, where we can get values different of the output by changing the values of inputs, and we can find the most important input which allow to effect directly on output, and the results based on process illustrate in figures.3-4 using equations.1-3 for member function both left and right and equation.4 for calculate the output, knowing that final output calculated by equation.5. Three dimensional diagram shows the relationship between inputs and output, which illustrate the influence of the inputs on output, and the figures two dimensional diagram shows the influence of one input on one output

Conclusion

The purpose of quantitative risk assessment is to estimates the values initiating events and outcomes probability. In this paper, three methods proposed for solve problem of uncertainty. FTA, ETA and Bow-tie are methods proposed for achieve the objectives using fuzzy sets, where the results are very powerful and precise. Results are very motivated to reach the purpose where both value precise initiating events and outcomes of scenarios, where these values calculated using FTA and ETA respectively, while precise value of risk using Bow-tie analysis. In conclusion, Fuzzy set is method very fit to precise the values of initiating events and outcomes scenarios in risk assessment.

References

Adam S. Markowski, M. Sam Mannan, Agata Kotynia, Dorota Siuta.2010. Uncertainty aspects in process safety analysis, Process Safety and Ecological Division, Faculty of Process and Environmental Engineering, Technical University of Lodz, 90-924 Lodz, ul. Wolczanska 213, Poland

Bouchon-Meunier B, Yager R, Zadeh L (1995) Fuzzy logic and soft computing.World Scientific, Singapore

Canos, L. & Liern, V. 2008, 'Soft computing-based aggregation methods for human resource management', Eur. J. Oper. Res., vol. 189, no. 3, pp. 669-681.

CCPS, Guidelines for Chemicals Process Quantitative Risk Analysis, 2nd edition, American institute of chemical engineers (AICHE), 2000.

Dawson JG, Gao Z (1994) Fuzzy logic control of linear systems with variable time delay. In: Proceedings of 1994 IEEE international symposium on intelligent control, pp. 5–10

Dubois D, Prade H (1980) Fuzzy sets and systems: theory and applications.Academic, New York

Dubois D, Prade H (1998) Soft computing, fuzzy logic, and artificial intelligence, soft computing a fusion of foundations, methodologies and applications, vol 2(1). Springer, Berlin Heidelberg New York, pp. 7–11

Dubois, D. & Prade, H. 1978, 'Operations on fuzzy numbers', Int. J. Syst. Sci., vol. 9, pp. 613- 626.

Eduardo Calixto, 2013. GAS and OIL reliability engineering, modeling and analysis, Elsevier

Epstein, S. & Rauzy, A. 2005, 'Can we trust PRA?', Reliab. Eng. Syst. Saf., vol. 88, no. 3, pp. 195-205.

Ericson, C.A. 2005, 'Fault tree analysis', in Ericson (ed.), Hazard Analysis Techniques for System Safety, John Wiley & Sons, Virginia, pp. 183-221.

Ferdous, R., 2006. Methodology for computer aided fuzzy fault tree analysis. Thesis Submitted To Memorial University of Newfoundland, Canada.

Gifford, M, Giltert S, Bernes I, 2003 Bow-Tie Analysis, Equipment Safety Assurance Symposium (ESAS).

Guh, Y.Y., Po, R.W. & Lee, E.S. 2008, 'The fuzzy weighted average within a generalized means function', Comput. Math. Appl., vol. 55, no. 12, pp. 2699-2706.

Gupta, S. & Bhattacharya, J. 2007, 'Reliability analysis of a conveyor system using hybrid data', Qual. Reliab. Eng. Int., vol. 23, no. 7, pp. 867-882.

Haimes, Y.Y. 2004, 'Fault trees', in Risk Modeling, Assessment, and Management, 2nd edn, John Wiley & Sons, New Jersey, pp. 525-569.

Hartford, D.N.D., and G. B. Baecher. 2004. Risk and uncertainty in dam safety. Thomas Telford, Ltd, London. 391 p.

Ireson, W. G., and Coombs, C. F. eds. 1988. Handbook of Reliability Engineering and Management, McGraw-Hill, New York, NY,

Kaplan, S., and Garrick, J. 1981. On the Quantitative Definition of Risk, Risk Analysis, vol.1, No.1

Kenarangui, R., 1991, Event-tree analysis by fuzzy probability. IEEE Transactions on Reliability, 40(1): 12–124. University of Tabriz, Tabriz

Mariana Dumitrescu and Toader Munteanu, 2001, Fuzzy Probability and Power System Safety. Dunarea de Jos Galati University, Electrical Engineering Department

Michael Beer, Scott Ferson, Vladik Kreinovich. 2012. Imprecise Probabilities In Engineering Analyses. Institute for Risk & Uncertainty, School of Engineering, University of Liverpool, Brodie Tower, Brownlow Street, Liverpool L69 3GQ, United Kingdom

Mohammad Moddarres, 1999. Reliability Engineering and Risk Analysis, Center for Quality and Applied Statistics Rochester, Institute of Technology Rochester, New York

Philley, J., 2006. Collar hazards with a BowTie, Chemical Processing. pp. 1-4.

Raman, R. 2004. Accounting for dynamic processes in process emergency response using event tree modeling. Center for Chemical Process Safety, 19th Annual International Conference - Emergency Planning Preparedness, Prevention, and Response. p.197-213.

Rasmussen, N.C. 1975. Reactor Safety Study: An assessment of accident risks in US, Commercial Nuclear Power Plants, Nuclear Regulatory commission, US.

Reason, J.T., 1997. Managing the Risks of Organizational Accidents, Burlington, VT: Ashgate.

Refaul Ferdous, Faisal Khan, Rehan Sadiq, Paul Amyotte, and Brian Veitch. 2011. Fault and Event Tree Analyses for Process Systems Risk Analysis: Uncertainty Handling Formulations. Faculty of Engineering and Applied Science, Memorial University, St. John's, NL, Canada.

Refaul Ferdous, Faisal Khana, Rehan Sadiq, Paul Amyotte, Brian Veitcha, 2009, Handling data uncertainties in event tree analysis, Faculty of Engineering & Applied Science, Memorial University, St. John's, NL, Canada.

Sugeno, M., Industrial applications of fuzzy control, Elsevier Science Pub. Co., 1985

Vesely, W.E., Goldberg, F.F., Roberts, N.N. & Haasl, D.F. 1981, Fault Tree Handbook, Systems and Reliability Research, in U.S.N.R. Commission (ed.) vol. Nureg-0492, Washington, D.C.

Wang, Y.M., Chin, K.S., Poon, G.K.K. & Yang, J.B. 2009, 'Risk evaluation in failure mode and effects analysis using fuzzy weighted geometric mean', Expert Syst. Appl., vol. 36, no. 2, pp. 1195-1207.

Wang, Y.M., Yang, J.B., Xu, D.L. & Chin, K.S. 2006, 'On the centroids of fuzzy numbers', Fuzzy Sets Syst., vol. 157, no. 7, pp. 919-926.

Xiaomin You, M. ASCE and Fulvio Tonon, M. ASCE, P.E. 2012. Event Tree and Fault Tree Analysis in Tunneling with Imprecise Probabilities, The University Texas of Austin, US.

Yang, G. 2007, 'Potential failure mode avoidance', in Life Cycle Reliability Engineering, John Wiley & Sons, Hoboken, NJ, pp. 194-235.

Zadeh, L.A. 1965, 'Fuzzy sets', Inform. Control, vol. 8, pp. 338-353.

Zadeh, L.A. 1978, 'Fuzzy sets as a basis for a theory of possibility', Fuzzy Sets Syst., vol. 1, no. 1, pp. 3-28.