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) (Phileey 2006; Ericson, 2005).
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.

2.2 Fuzzy Logic Fl And Fuzzy Set Theory FS

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

2.2.1 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).

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

\[
\mu_A(x) = \begin{cases} 
1, & a \leq x \leq b \\
\mu_A^L(x), & b \leq x \leq c \\
\mu_A^R(x), & c \leq x \leq d 
\end{cases}
\] (1)

\[
\mu_A^L(x) = \frac{x-a}{b-a} 
\] (2)

\[
\mu_A^R(x) = \frac{d-x}{d-c} 
\] (3)

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

\[
z = ax+by+c 
\] (4)

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

\[
\text{Final output}=\sum_{i=1}^{N} w_i z_i 
\] (5)

A FIS with five functional block described in Figure 3.
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

<table>
<thead>
<tr>
<th>Calculate probability using Boolean algebras method</th>
<th>Tank rupture due to reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>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-4</td>
<td>M1=1×10(^{-7})</td>
</tr>
<tr>
<td>B1=1.1×10(^{-3})</td>
<td>B2=1.1×10(^{-3})</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Calculate probability using fuzzy inference method</th>
<th>Tank rupture due to reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>IF</td>
<td>M1=1.71×10(^{-7})</td>
</tr>
<tr>
<td>B1=1.1×10(^{-3}) AND B2=1.1×10(^{-3}) AND B3=1.5×10(^{-4}) AND B4=1.5×10(^{-1})</td>
<td>M1=1.61×10(^{-7})</td>
</tr>
<tr>
<td>B1=0.504×10(^{-3}) AND B2=0.504×10(^{-3}) AND B3=1.5×10(^{-4}) AND B4=1.5×10(^{-1})</td>
<td>M1=1.82×10(^{-7})</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Calculate frequency of outcome using classical method</th>
<th>Safe disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td>large LPG leakage</td>
<td>1×10(^{-4})</td>
</tr>
</tbody>
</table>
| 0.9 | 0.85 | 0.1 | / | / | /

<table>
<thead>
<tr>
<th>Calculate frequency of outcome using fuzzy inference method</th>
<th>Safe disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1×10(^{-4}) AND 0.9 AND 0.85 AND 0.1 AND / AND /</td>
<td>THEN</td>
</tr>
</tbody>
</table>

**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.
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.

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