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Fuzzy risk modeling of process operations in the oil and gas refineries

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ABSTRACT

Operating several assets has resulted in more complexity and so occurrence of some major accidents in the refining industries. The process operations risk factors including failure frequency and the consequence components like employees' safety and environment impacts, operation downtime, direct and indirect cost of operations and maintenance, and mean time to repair should be considered in the analysis of these major accidents in any refinery. Considering all of these factors, the risk based maintenance (RBM) as a proper risk assessment methodology minimizes the risk resulting from asset failures. But, one of the main engineering problems in risk modeling of the complex industries like refineries is uncertainty due to the lack of information. This paper proposes a model for the risk of the process operations in the oil and gas refineries. The fuzzy logic system (FLS) was proposed for risk modeling. The merit of using fuzzy model is to overcome the uncertainty of the RBM components. This approach also can be accounted as a benchmark for future failures. A unified risk number would be obtained to show how the criticality of units is. The case study of a gas plant in an oil refinery is performed to illustrate the application of the proposed model and a comparison between the results of both traditional RBM and fuzzy method is made.

For the case study, 26 asset failures were identified. The fuzzy risk results show that 3 failures have semi-critical level and other 23 failures are non-critical. In both traditional and fuzzy RBM methods, some condenser failures had the highest risk number and some pumps were prioritized to have the lowest risk level. The unit with unified risk number less than 40 is in the non-critical conditions. Proposed methodology is also applicable to other industries dealing with process operations risks.

1. Introduction

Nowadays, the increasing diversity of products manufactured by refineries has made them to use many complex assets. So, occurring major accidents due to asset failures often is a natural event in the oil and gas refineries (Schouwenaars, 2008). Although the safety or environmental standards are rising rapidly, more and more failures have serious consequences in these areas (Arunraj & Maiti, 2007). Some failures may lead to stop a whole plant. However, the use of appropriate technological tools can provide information for making safety decisions with respect to plant designs and operations (Crowl & Louvar, 2002). Rising in the cost of maintenance is another problem of the refineries. It can be accounted as the second highest or even the highest element of operating costs. As a result, in only 30 years it was in the top of the league as a cost control priority (Arunraj & Maiti, 2007). Having effective maintenance strategies can reduce about 40–60% of an operating cost (Krishnasamy, Khan, & Haddara, 2005).

Obviously, a key element in the improvement of health and safety conditions at work is occupational risk prevention (Bevilacqua, Ciarapica, & Mazzuto, 2012). The use of different qualitative and/or quantitative risk assessment methods in the industrial accidents analysis has been undertaken in a number of papers (Antonioni, Spadoni, & Cozzani, 2007; Bi & Si, 2012; Brouwer & Blois, 2008; Farzam, Keivanloo, & Nikrooz, 2007; Kalantarnia, Khan, & Hawboldt, 2010; Khan & Abbasi, 1998, 1999, 2001; Khan & Amyotti, 2002; Márquez, Heguedas, & Iung, 2005; Melton & Springer, 2008; Nabhani, Jaderi, & Sa'idi, 2012; Pongsakdi, Rangsunvigit, Siemanond, & Bagajewicz, 2006; Rathnayaka, Khan, & Amyotte, 2012; Selvik & Aven, 2011). Some works have applied risk based maintenance (RBM) as a proper tool for assessing the

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industrial assets risks (Apeland & Aven, 2000; Anvaripour, Sa'idi, Nabhani, & Jaderi, 2013; Axelsen, Knudsen, & Johnsen, 2003; Bertolini, Bevilacqua, Ciarapica, & Giacchetta, 2009; Chang & Wang, 2010; Jaderi, Jaafarzadeh, Ibrahim, Nbavi, & Abdollah, 2012; Jiang, Wang, Lung, Guo, & Li, 2010; Khan & Haddara, 2003; Krishnasamy et al., 2005; Márquez, 2007, Ch. 9, pp.107–126; Noroozi, Khan, Mackinnon, Amyotte, & Deakon, 2012).

In spite of these worth literature, there is still much lacking and uncertain information, implicit in the variables, models and subjectivity, especially in the area of a very rare event like major accident hazards. In practice, the main source of data available is shift operator. To hazard identification, anyone should refer to the field, not in the office (Norman, 1991). So, without uncertainty, one may argue risk assessment is not necessary (Wang, Chan, Yee, & Diaz- Rainey, 2011). Uncertainty may result from lack of information, lexical impression, incompleteness and inaccuracy of measurement (Yaquiong, Man, & Zhang, 2010). In view of this, this paper proposes the modeling of the traditional RBM method with fuzzy logic to incorporate uncertain variables. It should be noted that there are other approaches for expressing uncertainty, such as evidence theory, Bayesian methods, rough sets, and interval analysis, too (Siuta, Markowski, & Mannan, 2013). Fuzzy theory has been proven as a useful approach to the risk evaluation of many sciences, because of the imprecision of the data and the frequent lack of quantitative information. After nearly a half century years of research, several studies of many authors have showed the worth of this theory as a practical engineering and problem-solving tool (Markowski, Mannan, & Bigoszewska, 2009; Markowski & Mannan, 2009). Fuzzy set theory was applied widely in many resources for risk modeling (Bajpaia, Sachdevab, & Gupta, 2010; Bevilacqua et al., 2012; Celik, Mirilavasani, & Wang, 2010; Chen, Huang, & Chakma, 2000; Elsayed, 2009; Gomase, Jain, & Bhure, 2012; Grassi, Gamberini, Mora, & Rimini, 2009; Hadjimichael, 2009; Haigu, Jiawei, Pengfei, 2006; Jamshidi, Yazdani-Chamzini, Haji Yakhchali, & Khaleghi, 2013; Kentel & Aral, 2004; Li & Suo, 2006; Markowski, Mannan, & Bigoszewska, 2009; Markowski & Mannan, 2009; Markowski, Mannan, Bigoszewska, & Siuta, 2010; Markowski, Mannan, Kotynia, & Pawlak, 2011; Miri Lavasani, Yang, Finlay, & Wang, 2011; Shiliang, Min, Yong, & Runqiu, 2012; Siuta et al., 2013; Wang et al., 2011; Xu, Tang, Xie, Ho, & Zhu, 2002; Zolotukhin & Gudmestad, 2002). Khan, Sadiq, and Haddara (2004) and Kumar and Maiti (2012) are among the rare authors applied fuzzy RBM model. Khan et al. (2004) presented a simple and structured risk based inspection and maintenance (RBIM) methodology. The proposed methodology used fuzzy logic to estimate risk by combining (fuzzy) likelihood of occurrence of and its (fuzzy) consequence. Their consequence factors considered production loss, safety and environment. Kumar and Maiti (2012) refer to the Arunraj and Maiti (2007) which devised a methodology for maintenance policy selection in chemical industry taking risk and cost as the criteria. The consequence factors in both papers seem not to be adequate for having a comprehensive risk assessment of asset failures. Among many RBM methods proposed by several authors, one which was introduced by Márquez (2007, Ch. 9, pp.107–126) for the petrochemicals considers more useful risk factors. Furthermore, this method is simple and effective because it can calculate the risk numbers by the risk formula. Jaderi et al. (2012) localized these risk factors for the first time at the Fajr petrochemical company in Iran. Then, its localized scales and applications for the refineries were described (Anvaripour et al., 2013). However, they didn't model the RBM with any uncertainty approaches. The same RBM factors proposed in this paper.

There is no domestic risk management framework for process operations of Iranian refineries to prevent or reduce risks of the asset failures. The main objective of the paper is to model the process operations of refineries using the fuzzy set theory. The framework of the work done for this paper has been shown in Fig. 1.

Delphi method developed in the 1950s in Santa Monica, California (Nowack, Endrikat, & Guenther, 2011; Okoli & Pawlowski, 2004; Vidal, Marle, & Bocquet, 2011). It has been characterized as a method for structuring a group communication process to allow a group of individuals, as a whole, to deal with a complex problem in an efficient way (Turoff & Linstone, 2002). Delphi method has been identified as a successful qualitative risk assessment technique in order to collect the data necessary in hazard identification check lists (Arunraj & Maiti, 2007). So, this technique was applied for data collection in this paper.

As a novel scientific work for the risk assessment modeling in Iranian refineries, the proposed RBM model is performed on fuzzy logic toolbox of MATLAB using Mamdani algorithm of fuzzy inference system (FIS). A typical case study for a gas plant of Abadan oil refinery is performed and a comparison between risk assessment in the traditional and fuzzy RBM methods is made. Then, the assets are prioritized according to their criticality levels. Applying the RBM model increases the safety of system, reduces the environmental impacts and maintenance costs, allocates the spare assets where necessary, and finally leads to the prioritization of the process operations according to their risk levels. Detailed description of the methodology is presented in the subsequent sections.

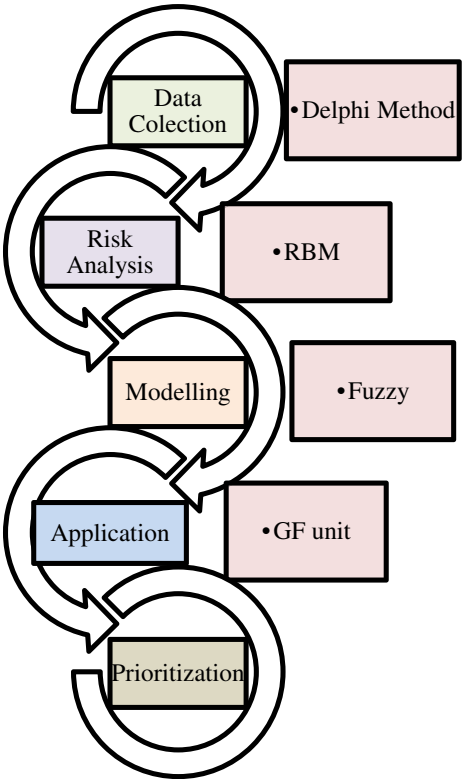

Fig. 1. The framework of this paper.

2. Traditional RBM methodology

RBM methodology provides a tool for maintenance planning and decision making to reduce the probability of failure of equipment and the consequences of failure (Krishnasamy et al., 2005). As some advantages, RBM can be introduced as a comprehensive hybrid or quantitative and qualitative risk assessment technique which can be applied to all types of assets irrespective of their