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Fuzzy based risk prioritisation in an auto LPG dispensing station

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A B S T R A C T

A fuzzy rule based inference model assessing the failure modes for risk ranking in FMEA to manage risks and make maintenance decisions is applied to a LPG refuelling station in this paper. Normally in FMEA, risk priority number (RPN) is determined by multiplication of feature scores that are inferred from the degree or probability of occurrence, severity and non detection of the problem, without taking into consideration the relative importance of factors. In fuzzy approach, linguistic assessment of factors is evaluated to obtain risk priority number. A rule based fuzzy inference engine generates the priority ranks of identified failure modes. Direct evaluation is possible with the aid of grey theory by assigning weights to the features in the absence of expertise to develop an inference rule base. The GRA approaches can solve the problem of risk prioritising, which needs expertise to develop rule base while building the fuzzy inference system. By applying fuzzy FMEA and fuzzy logic with grey relational approach (GRA), expert linguistic opinions are used to rank the identified failure modes and the results are presented. The risk of the failure modes are ranked in an inclusive approach based on the fuzzy domain projections. It is effective and feasible to handle various types of uncertainties, such as incompleteness, fuzziness, imprecision, and so on, in the risk analysis process.

1. Introduction

A significant number of studies have applied fuzzy logic to identify, quantify risks, enhance safety and also for maintenance functions. Efforts were taken to assess the state of big diesel engine by calculating the fuzzy distance between the fuzzy vector and standard fuzzy vector (Wei et al., 2009). Guo et al. (2009) developed a model, in which a three-layer BP neural network is combined with fuzzy comprehensive evaluation and demonstrated with an application in an ethylene plant for allocating maintenance resources based on criticality evaluation.

Fuzzy Probabilities of basic events and output events are derived from fuzzy input data and fuzzy utility value (FUV) is introduced to perform risk assessment for natural gas pipelines (Shahriar et al., 2012). Works on risk based maintenance (RBM) optimization suggest a fuzzy inference system (FIS) to minimize the suboptimal prioritizations of functions in the FFR (functional failure risk) analysis performed using an illustrative tailor-made risk matrix. (Ratnayake, 2014). A fuzzy logic system (FLS) was proposed for risk modelling to overcome the uncertainty of the RBM components in an oil refinery (Sa'idi et al., 2014). The basic event occurrence probability was quantified and investigated by a hybridised approach using fuzzy set theory and weight analysis (Chen et al., 2014). Dynamic sequential accident models (DSAMs) utilises precursor data to estimate the posterior risk profile quantitatively. DSAM also offers updates on the failure probabilities of accident barriers and the prediction of future end states (Al-shanini et al., 2014). A left–right (L-R) bell-shaped fuzzy number is applied for barrier and operational risk analysis (BORA-Release) method and an α-cut operation is introduced to conduct the arithmetic operations of the fuzzy number, and a defuzzification method with total integral value is chosen to match the α -cut operations and acquire complete information for the fuzzy numbers (Huang et al., 2015).

In FMEA literatures based on fuzzy sets, the approaches have mostly concerned with the fuzzy inference approach by using a rule-base (Bowles and Peláez, 1995; Chin et al., 2008; Guimarães and Lapa, 2004a, 2004b, 2007; Pillay and Wang, 2003; Sharma et al., 2005; Tay and Lim, 2006; Xu et al., 2002; Li et al., 2010). Linguistic terms were assigned to the factors and considering them as inputs, an if-then rule base was created for risk evaluation. The outputs were termed as risk (Chin et al., 2008; Guimarães and Lapa, 2004a, 2004b), the critically failure mode (Xu et al., 2002), priority for attention (Pillay and Wang, 2003), and fuzzy RPN (Sharma et al., 2005; Xu et al., 2002) in the fuzzy FMEA studies which consider the fuzzy rule-base approach. A FMEA

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based on fuzzy logic was implemented in diesel engine systems (Xu et al., 2002).

Guimarães and Lapa (2004a) applied fuzzy concepts to analyze the failures in a chemical and volume control system of pressurised water reactor. They also implemented a fuzzy logic system for risk ranking enhancement purpose in an auxiliary feed water system. (Guimarães and Lapa, 2004b). Guimarães and Lapa (2007) adopted fuzzy rule based inference for risk analysis in nuclear power plant as a contemporary approach. Yeh and Hsieh (2007) conducted fuzzy FMEA assessment for a sewage plant. Wang et al. (2009) made risk evaluation in FMEA using fuzzy weighted geometric mean. Sharma et al. (2008) developed a fuzzy logic-based decision support system.

Tay and Lim (2006) simplified the FMEA methodology based on fuzzy logic by proposing a generic method to reduce the number of rules for inference system, provided by experts to model fuzzy RPN for performance evaluation in a semiconductor manufacturing plant. Pelaez and Bowles (1996) applied fuzzy cognitive map to FMEA. Pillay and Wang (2003) proposed FMEA with fuzzy reasoning and grey relation for marine industry to conquer the traditional weaknesses in risk evaluation. Braglia et al. (2003) used a fuzzy TOPSIS in FMEA. Keskin and Ozkan (2009) proposed FMEA supported by fuzzy ART algorithm.

A product design system based on fuzzy FMEA was developed by Chin et al. (2008). Abdelgawad and Fayek (2011) implemented risk management in the construction industry through combined fuzzy FMEA and fuzzy AHP. Tay and Lim (2010) enhanced FMEA methodology with fuzzy inference techniques and evaluated the performance of the fuzzy RPN models in the test handler process of a semiconductor manufacturing plant. Hao-Tien Liu and Yieh-lin Tsai (2012) utilised fuzzy analytic network process method to identify critical hazard causes and types and utilised fuzzy FMEA based inference approach to assess the causes for a telecom engineering concern in South Taiwan. In a chemical process industry, risks are prioritized using risk priority matrix and mitigation strategies are selected based on FMEA. Fuzzy estimates obtained for the risk factors and bow-tie analysis are used to calculate the aggregated risk probability and impact (Aqlan and Mustafa, 2014). Mentes and Ozen (2015) integrated Ordered Weighted Geometric Averaging (OWGA) and Generalized Mixture Operators (GMOs) to improve safety during design. The proposed approach is experimented with a motor yacht fuel system. Zhou and Thai (2016) applied fuzzy set and grey relational analysis to evaluate the failure modes in oil tankers transporting bulk crude oil. Relative ranking is reflected by grey theory approach. The results show the both the methods work similar.

Researchers have conducted numerous investigations to enhance the FMEA methodology by integrating artificial intelligence approaches. There are significant efforts made in FMEA literatures to overcome the shortcomings of the traditional RPN (Wang et al., 2009; Liu, 2013). The risk parameters O, S, and D in fuzzy FMEA are expressed as linguistic fuzzy terms in studies with expert opinions. The traditional 10 point scale for O, S, and D risk factors are interpreted as linguistic variables.

Increased public awareness for environmental protection and stricter pollution control norms propagating use of efficient fuels have steadily pulled to the trend for LPG conversion for auto fuel and diversion of domestic fuel to auto fuel at a steady growth @ 8% p.a. in LPG Consumption in India (Apurva Chandra, 2010). Automotive Liquefied Petroleum Gas (LPG) (BIS 14861) is a mixture of light hydrocarbons primarily Predominantly 100% Propane or combinations of Propane: Butane 'mixes' derived from petroleum, which is gaseous at ambient temperature and atmospheric pressure, is liquefied at ambient temperature with application of moderate pressure. LPG due to its inherent properties is susceptible to fire, explosion and other hazards. Such hazards can have an impact on the process, property, equipment, plant personnel and public. Various additives are added to detect its dispersion. Meticulous understanding of the failure of systems and its components, the causes, the consequences and the actions needed to avoid them is highly recommended for loss prevention in process industries. Fuzzy logic combined with expert elicitation was employed in a LPG refuelling station to quantify basic event failure probabilities by qualitative information processing without reliance on historical quantitative failure statistics. (Rajakarunakaran et al., 2015).

In this work a Fuzzy FMEA model is proposed and applied to an auto LPG refuelling station. Based on the literature review, the application of Fuzzy based FMEA to an auto LPG refuelling station is a important task required for defined safety decision making process. The proposed framework of fuzzy FMEA exhibits two advantages: (i) an ability to assess the failure modes of engineering systems using expert opinions articulated in linguistic terms; (ii) an ability to handle various types of uncertainties, such as imprecision, fuzziness, incompleteness of quantitative risk assessments. The rule base development in the case of fuzzy FMEA can be replaced with a multi-criteria decision making problem (MCDM) approach and the techniques may be applied to yield a ranking strategy. Grey relational analysis (GRA) is selected as an approach to this problem to prioritise and rank the events in the absence of rule base.

The uniqueness or novelty of this study are: (i) a use of linguistic values in terms of expert opinion, (ii) development of fuzzy interference rules to apply for an auto LPG refuelling station (iii) an integration of the proposed fuzzy rules into the inference system (iv) determination of the fuzzy RPN by defuzzification and thereby achieving the systems risk priority ranking (v) Application of linguistic expert opinions for multi criteria decision making (vi) Incorporation of grey theory for direct evaluation of failure modes by assigning weights to the features considering the relative importance of factors (vii) Rule based inference is replaced by the application of a grey relational framework. To reveal the feasibility of the proposed frameworks, the outputs generated are compared with the conventional FMEA risk analysis process.

2. Fuzzy FMEA

FMEA is a tool widely used to make out the probable failure modes of a process or a product. FMEA was first projected in 1963 by NASA as a formal system analysis method for their reliability needs. Then in 1977, it was put into practice by Ford Motors (Gilchrist, 1993). Since it emerged as a influential tool extensively used for risk analysis and reliability studies of systems in a broad scope of industries, together with construction, automotive, aerospace, nuclear, and electro-technical. Table 1 lists the FMEA scale to compute the three factors, occurrence (O), severity (S) and detection (D) to calculate RPN value which is the product of the factors. The table show that the customary FMEA measures the probability of occurrence, severity and the probability of non detection using five scales and scores of 1–10. The failures can be eliminated or reduced by ranking the failures for corrective action by virtue of their risk implication.

The well accepted FMEA safety analysis method suffer from several impediments. In traditional approach, the risk factors are understood to be similarly important (Braglia, 2000). Many operation and maintenance experts were found to give more weight to non detection factor. The gathered failure data may often be unreliable or partial. Therefore based on knowledge and expertise of experts the risk factors are assessed. The risk factors are hard to be calculated exactly due to the often questionable and debatable mathemaical formula for calculating RPN mathematically. No rationale to multiply O, S, and D is found. From Table 1 it can be found that a non linear occurrence scale is considered with linear severity and non detection scales. Multiplying the factor scores after conversion of probability to a linear scoring system is