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A risk matrix analysis method based on potential risk influence: A case study on cryogenic liquid hydrogen filling system

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ABSTRACT

A risk matrix analysis framework is proposed for risk assessment and prioritization based on potential risk influence (PRI). First, a new principle for risk level assignment considers the potential impacts of risk, including controllability, criticality, manageability and uncertainty, is established. Next, the impacts of potential risk are divided into two risk influence factors in risk matrix: probability and consequence influence factor. A fuzzy probability method is used to calculate the failure probability of basic events when appropriate reliability data is unavailable. To take the dependence of basic events into account, Bayesian belief network models established to calculate the likelihood of failure. Finally, to demonstrate the validity of the proposed method, a risk assessment and a risk ranking process are performed for a cryogenic liquid hydrogen filling system (CLHFS). The results of the case study confirmed that the proposed methodology successfully manages risk level inconsistency, and is altogether a feasible and reasonable tool for risk management.

1. Introduction

Risk assessment and risk ranking are tasks that are necessary to ensure acceptably low risk level in industrial processes. Risk assessment involves a wide range of quantitative and qualitative techniques, such as fault tree analysis (FTA), event tree analysis (ETA), failure mode and effect analysis (FMEA), Markov models, and GO-flow method (Khan et al., 2015; Mandal and Maiti, 2014; Ruijters and Stoelinga, 2015). Risk matrix, which is a semi-quantitative risk assessment technique, is a practical tool for risk ranking and management for engineering systems. It is commonly utilized in space, nuclear, and chemical processing industries (Abd Majid et al., 2014; Chen et al., 2008; Lu et al., 2015; Yi et al., 2013).

According to United States MIL-STD-882D (USA, 2000), risk is defined as a multiplication of probability and consequence, and risk matrices are the most appropriate tool for risk assessment. The primary objective of a risk matrix is to rank and prioritize risk for the benefit of decision makers. Risk assessment is a crucial component of any successful processing industry. However, there is no standardized practice for building a risk matrix – universal methods for risk level assignment remain particularly elusive (Anthony Cox Jr, 2008; Duijm, 2015).

Normally, there are two basic methods for establishing categories in a risk matrix: one is based on quantitative risk scores calculated by ordinal numbers (Flage and Røed, 2012), the other involves subjective judgments, also called "IF–THEN" method (Markowski and Mannan, 2008). Quantitative risk scoring involves a combination of probability and consequence factors, in accordance with the consistency axioms established by previous researchers (Anthony Cox Jr, 2008). Then, research suggests that utilizing linear scales is an appropriate method for expressing probabilities and consequences (Ni et al., 2010). Flage and Røed concluded that the essential difference between linear scales and

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logarithmic scales is that when categories are linearly spaced, risk scores should be calculated by multiplying category ordinal numbers, and when categories are logarithmically spaced, risk scores should be calculated by adding category ordinal numbers (Flage and Røed, 2012). Typically, risk level cells in a risk matrix are symmetrically distributed; the risk matrix can then usually be divided into three classes, "easy", "standard", and "hard" based on distances from the origin (Markowski and Mannan, 2008). The subjective judgment approach for establishing risk categories, conversely, is usually performed based on empirical engineering knowledge such as the dealing of major-hazard aversions (Duijm, 2015).

Researchers have added the knowledge dimension, which is qualitative (subjective) rather than quantitative, to risk matrices (Aven, 2013). The risk level in a risk matrix was once determined solely by quantitative risk scores, and any other subjective judgments were considered to violate the definition of risk (Anthony Cox Jr, 2008; Flage and Røed, 2012). In a real-world industrial plant, however, risk level assignment is influenced by a wide variety of factors including controllability, criticality, manageability, and uncertainty (Flage and Røed, 2012). To the author's knowledge, there have been no published studies regarding the influence of any other aspects of risk for risk ranking and assessment.

Due to restrictions inherent to risk matrix structure (e.g. where the number of risk levels is smaller than the number of risk cells), conventional risk matrices (CRM) show a notable drawback called "risk ties". The Borda ordinal method can be used to eliminate risk ties (Jin et al., 2012). However, in some cases, it is unable to eliminate them completely. Increasing in the number of probability and consequence categories may improve the risk resolution (Markowski and Mannan, 2008). In addition to the knowledge dimension mentioned above, researchers have established a three-dimensional risk matrix analysis method which includes a protection dimension (Jin et al., 2012). Nowadays, the continuous probability consequence diagram (CPCD) is proposed, which manages the resolution of CRMs (Duijm, 2015).

The objective of this study is to propose a risk matrix analysis framework based on CPCD method and conventional risk matrix techniques. The proposed method combines potential risk influence information and quantitative risk scores to facilitate comprehensive risk analysis. The remainder of this paper is organized as follows: Section 2 provides a thorough review of risk matrices, Section 3 presents the proposed risk matrix analysis approach. Section 4 explores a fuzzy probability method based on the judgment of industry experts. Section 5 applies the proposed approach to a risk assessment case study of a cryogenic liquid hydrogen filling system. Section 6 provides a brief summary and conclusion.

2. Overview of risk matrix

Risk matrix is a semi-quantitative risk assessment tool commonly utilized for risk analysis and evaluation in a variety of industries. Traditionally, the risk levels in matrix are depended on a combination of probability and consequence ordinal numbers forming discrete points. In other word, the risk matrix also is a mapping of probability and consequence to risk, with a mapping function monotonically increases. Risk levels are usually depicted using different colors: red typically marks the unacceptable risk level, yellow or orange marks risks reduced, and green generally represents acceptable risks.

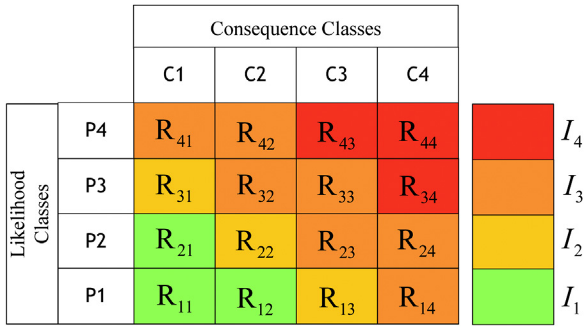

Fig. 1 – 4 × 4 risk matrix.

There are four basic steps to build a risk matrix (Markowski and Mannan, 2008):

(1) Define the categories and scales of consequence and probability levels,
(2) Define categories and scales of the output risk index,
(3) Establish risk-based rules,
(4) Create a graphical depiction of the risk matrix.

Normally, probability defined as M categories and consequence defined as N categories, the larger M and N are, the more cognition the risk experts possess. A 4×4 risk matrix is shown in Fig. 1. R_{ij} denotes the risk matrix cells in which, i is the ordinal number of probability, j is the ordinal number of consequence, and I is the risk level marked in four colors ($I_1 < I_2 < I_3 < I_4$).

The risk matrix defined using the following classification function:

$$\mathbf{R} = g(P_i, C_j) = [R_{ij}], \quad i = 1, 2, \cdots M; \quad j = 1, 2, \cdots N. \tag{1}$$

where R_{ij} is the risk level for the probability category of i and the consequence category of j. P_i and C_j are probability and consequence categories, respectively.

3. Methodology

The proposed risk matrix is a PRI-based methodology. Certain necessary aspects of risk, such as controllability, criticality, manageability and uncertainty cannot be characterized by quantitative risk scores in CRM. In this study, these aspects serving as PRI integrates into risk matrix during risk level assignment.

3.1. *Calculating risk index based on PRI*

Risk level assignment in CRM relies on the risk index calculated by the probability and consequence ordinal numbers. Flage and Røed (2012) first put forward the concepts of criticality, manageability, and uncertainty, which are aspects or characteristics of risk other than likelihood and consequence. These aspects influence risk analysts to make decision makers. Actually, these aspects should be accounted when assigning risk level and decisions making.

In this paper, in order to account the influence of these aspects in risk matrix, the potential risk influence is divided into two categories: probability and consequence. Such as the uncertainty represents the happening opportunity of unexpected events, controllability and criticality express the consequence severity or emergency. Based on this thought,