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Selection of inherently safer preventive measures to reduce human error

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ABSTRACT

The inherent safety concept has been introduced to overcome the shortcoming of traditional hazard assessments by allowing modification to be made at any stage of life-cycle of a process plant. However, most of the proposed inherent safety modifications were suitable to prevent fire, explosion and toxic hazard but less attention on the human factor. Therefore, this paper introduces a technique to assess and improve the preventive measure relevant to human factor aspect using inherent safety concept. Analytic Hierarchy Process model integrated with fuzzy logic known as FAHP was employed to rank the identified inherently safer preventive measures. The model was applied refers to the Piper Alpha offshore disaster with the main intention is to prevent similar incident occurring in the future. The result shows the capability of the proposed methodology in selecting the best inherently safer preventive measure together with its implementation cost and maturity time without requiring lots of precise information to translate experts' opinion from human performance's point of view.

1. Introduction

After many years of improvements in technical safety methods and process design, many organizations have concluded that the incident rates, process plant losses and profitability have reached the highest conditions which illustrate that further improvements seem impossible to achieve (CCPS, 1994). The main concern is large scale disasters still occur especially in the chemical processing industry (CPI) even in organizations with good general safety records. The common causal factor in this disaster is the problem of human error (HE). HE has been widely recognized as the main contributor in most industrial incidents worldwide that caused loss of life, injury to personnel and property damage (Qi et al., 2012). A release of cyclohexane at Flixborough, England in 1974, Ocean Ranger Platform collapse at Newfoundland, Canada in 1982, release of methyl isocyanate (MIC) at Bhopal, India in 1984 and a major fire at Milford Haven, UK in 1994 are classical example of major industrial incidents due to HE. It has been estimated that over 80% in chemical and petrochemical industries (Kariuki and Löwe, 2007), 50–70% at nuclear power facilities (Li et al., 2010), and 80% in shipping industries (Mokhtari et al., 2012) of major incidents have HE as a cause. Thus, the paper proposed a methodology to prevent or reduce HE and increase human performance level by identifying appropriate improvement or remediation preventive measure using Inherent Safety (IS) concept.

2. Literature review

Behavioural safety, also known as behavioural based safety (BBS) programme, is one of the successful techniques to improve HE in industrial settings. It was introduced and implemented successfully in various industrial settings since 1970s (Krause et al., 1999; Quintana, 1999; Williams and Geller, 2000). Although BBS methods are consistently effective at reducing the frequency of HE, they can only work optimally if implemented throughout an organization. Usually, employees do not participate actively in observation and feedback sessions and help to implement BBS intervention procedures (DePasquale and Geller, 1999). The problem is worsening because BBS is not cost effective due to the continuous training and behavioural checklist printing needed.

However, major incidents that related to human factors such as the tragic explosion at the BP Texas refinery plant still occur. Thus, it

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is important to develop a new concept to prevent or reduce HE and increase human performance level in process industry.

A lot of methodologies on improvement strategies proposed with IS concept is believed to give the best result. The IS concept was originally pioneered by Trevor Kletz in the early 1970s (Kletz, 1984) applied to environmental and industrial hygiene. Since then, a number of researchers had addressed this concept with different approaches for various area. A summary is presented here; highlighting only information considered essential to this discussion.

In the early 1990s, the EU INSIDE Project (INSIDE, 1997) started to introduce inherent safety, health, and environmental protection (ISHE) within the European industry by evaluating the effects of airborne chemicals to health. Exxon Chemical's inherent safety review process had utilised several existing inherent safety evaluation tools together at various points in the life cycle process of their plants (French et al., 1996). Rohm and Haas major accident prevention program based on potential accident consequence analysis utilised the concept for the implementation in the process plant (Hendershot, 1991; Berger and Lantzy, 1996). Khan and Amyotte (2004, 2005) proposed a new indexing technique known as integrated inherent safety index (I2SI), which is intended to be applicable throughout the life cycle of process design. A new approach has also been introduced (Tugnoli et al., 2007) in order to assess inherent safety of process alternatives based on consequence estimation using key performance indicator.

Most of the published methodologies are not directly associated with inherently safer preventive measures for human factor improvement since the concepts were developed purposely for the assessment of process improvement to avoid fire, explosion and toxic hazards. However, CCPS (2009) had discussed the examples of inherently safer chemical processes from human factor aspect but it is not comprehensive. Therefore, there is a need to urgently focus on human factor preventive measures at early design stage or plant operation to prevent or reduce the likelihood of HE.

This paper introduced the human factor guidelines using IS concept as shown in Table 1. The IS descriptions and preventive measures are proposed which could be modified to suit the applicability of the process or industry.

In order to select the best inherently safer preventive measures to be implemented in the processing industry, the proposed human factor guidelines is integrated with Fuzzy Analytic Hierarchy Process (AHP) method or known as Fuzzy AHP (FAHP). The AHP model first proposed by Saaty (1980), is suitable to deal with complex systems in making decision of choice from several alternatives using both qualitative and quantitative variables which includes the consideration by experts' opinion. However, AHP is criticized due to its inability to adequately handle the inherent uncertainty and imprecision in the pair-wise comparison process (Deng, 1999). The traditional AHP cannot really reflect the human thinking style (Kahraman et al., 2003). This problematic method also uses an exact value to express the experts' opinion in comparison of alternatives (Wang and Chen, 2007).

Therefore, AHP was integrated with fuzzy logic to overcome all the shortcomings since the experts are commonly more confident to give interval judgements in the form of triangular fuzzy number (TFN) than fixed value judgements. A few researches had been proposed previously using FAHP model. The FAHP method was used for risk assessment to get the plant relative membership grades (Ma et al., 2010). The study is capable to estimate, not only the order of harmfulness, hazard and unsafe condition, but also assess the order of the risk of potential accidents to happen among all the chemical plants. The FAHP model was proposed to evaluate the work safety in hot and humid environments in terms of safety index, safety grade and early warning grade (Zheng et al., 2012). The model had also been used for planning and design tender selection in public office buildings (Hsieh et al., 2004), to assess national competitiveness in the hydrogen technology sector (Lee et al., 2008), architectural design (AD) proposal selection (Hao et al., 2009) and selection of optimum underground mining method for Jajarm Bauxite Mine, Iran (Naghadehi et al., 2009). Most of the proposed methods emphasised on the hardware or process modifications but less focus on human factor especially associated with the IS concept.

Latest proposed research on solution processes of FAHP method is based on extent analysis method. The Chang's extent analysis method is relatively easier while comparing to the other approaches on FAHP (Chang, 1996). It has been employed in quite a number of applications (Celik et al., 2009; Jia et al., 2012; Sarfaraz and Jenab, 2012; Anagnostopoulos et al., 2007). However, this method is found unable to derive the true weights from a fuzzy crisp comparison matrix. The weights determined by the Chang's extent analysis method do not represent the relative importance of decision criteria or alternatives at all. This weakness was proven by Jia et al. (2012) and Wang et al. (2008).

Thus, in this study, the traditional FAHP method is proposed to determine the weights of the inherently safer preventive measures. The same method is used to estimate the implementation cost and maturity time for each of inherently safer preventive measures. The evaluation result is supported by questionnaire data carried out to analyse the experts' opinions and rank the inherently safer preventive measures comprehensively.

3. Model for inherently safer preventive measures using fuzzy analytic hierarchy process (FAHP)

The methodology to evaluate inherently safer preventive measures using FAHP is demonstrated in Fig. 1. The details of each step are further illustrated in this section.

Step 1: *Establish the preventive measures according to IS principles*

The preventive measures are established according to literature reviews or experts' opinion. The preventive measures should refer to four principles of IS concept, i.e. minimization, substitution, moderation and simplification, as listed in Table 1.

Step 2: *Data collection through questionnaires among the experts'*

A set of questionnaires was prepared, and the experts' are invited to give their opinion on the most important when comparing between two or more criteria. It is easier and more humanistic for experts' to assess linguistic variables in which the information is too complex to be defined in a crisp value.

In this study, three major elements are considered; the preventive measures, implementation cost, maturity time. The previous proposed linguistic scale (Anagnostopoulos et al., 2007; Zhu et al., 1999; Lamata, 2004) is modified to suit its application in this study. Chen and Ku (2008) had suggested that the selection of TFN (triangular fuzzy number) is better than TrFN (trapezoidal fuzzy numbers) on account of the simpler form since using different types of fuzzy numbers have the same results. Therefore, TFN is applied in this study.

Step 2(*a*): *Preventive Measure*

The main purpose of this element is to identify the best among the proposed preventive measures referring to the experts' opinion. The linguistic scale is provided to justify the condition of each preventive measure as presented in Table 2.