Safety Science 93 (2017) 16–28

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Fuzzy probabilistic expert system for occupational hazard assessment in construction

Mehran Amiri [a,*], Abdollah Ardeshir [b,c], Mohammad Hossein Fazel Zarandi [d]

[a] Department of Civil Engineering, Payame Noor University, Tehran, Iran
[b] Civil and Environmental Engineering Faculty, Amirkabir University of Technology, Tehran, Iran
[c] Environmental Research Center, Amirkabir University of Technology, Hafez Ave., Tehran, Iran
[d] Department of Industrial Engineering and System Management, Amirkabir University of Technology, Hafez Ave., Tehran, Iran

ARTICLE INFO

Article history:
Received 18 July 2016
Received in revised form 8 September 2016
Accepted 11 November 2016

Keywords:
Construction
Fuzzy-probability logic
Rule base expert system
Safety risk assessment

ABSTRACT

Considering the extensive growth of the construction industry in developing countries, the trend of occupational accidents in this sector is growing in recent years. In this regard, developing a hazard management process with a proactive vision makes it possible to identify and prioritize risky points in construction sites and apply preventive measures. Hence, in this paper, a fuzzy probabilistic rule-based expert system is developed for occupational hazard assessment. A fuzzy probabilistic system permits us to model uncertainties related to accident databases and the randomness due to environmental, natural, or time changes. Merging randomness into the occupational risk assessment problem in the construction industry enables the authorities to manage hazards proactively and brings about some practical benefits. The proposed fuzzy probabilistic model benefits from a rule base generated based on fuzzy risk-based statistical and data mining analyses of accident database along with a comprehensive literature review and interviews with experts. This model is tested on four major construction case studies. Through an intensive validation process, the model was successfully analyzed and ranked the risks of different types. The results are encouraging and the model can be implemented in different construction projects.

1. Introduction

The construction industry, as a function of world population, has grown extensively in the past years. Hence, more shelters, workspaces, infrastructures and facilities are needed, which expand the construction market as a substantial sector in every economy (Awwad et al., 2016). The construction sector worldwide accounts for more than 11% of global GDP in 2016, and it is predicted that it will constitute 13.2% of world GDP by 2020 (Reuters, 2016). However, despite the recent improvements in the field of construction safety, the accident rate is still much higher than in most of the other industries (Sousa et al., 2015). Such high injury rates may be attributed to the characteristics of construction work in particular, which necessitate the use of heavy machinery and working under harsh conditions (Hallowell and Gambatese, 2009).

Risks with high levels of uncertainty are inherent and an inevitable part of a construction project. Hence, it is wise to place greater emphasis on safety and risk management in construction projects (Wehbe et al., 2016). In this regard, great effort has been driven to develop safety systems, hoping to prevent accidents and improve safety performance (Awwad et al., 2016).

It is also clear that the most effective approach to improving safety performance is to avoid accidents and reduce uncertainty before accidents happen (Cooke, 1997; Gambatese et al., 2008). Hence, assessment of safety related risks is the foundation in which safety management is built upon, and therefore, risk assessment is considered an essential component of safety management systems (Langford et al., 2000; Pheng and Shiua, 2000; Cheng et al., 2004; Jung et al., 2008).

In this regard, it is noteworthy that Haslam et al. examined 100 incidents in the construction industry and recognized that the lack of proper risk management processes is one of the hidden factors in this field. Based on their research, 84% of these accidents are predictable provided risk management is applied properly (Haslam et al., 2005).

Different methods have been used so far to assess the risks associated with occupational safety; within them, Failure Mode and Effects Analysis (FMEA) is known as one of the most common methods (Falcone et al., 2013). Here, fuzzy logic can also be

* Corresponding author at: Payame Noor University, 71th Street, Moallem Blvd., Mashhad, Iran.

E-mail addresses: mehran.amiri@pnu.ac.ir (M. Amiri), ardeshir@aut.ac.ir (A. Ardeshir), zarandi@aut.ac.ir (M.H. Fazel Zarandi).

http://dx.doi.org/10.1016/j.ssci.2016.11.008
0925-7535/

combined with the FMEA method to overcome the shortcomings of the traditional FMEA approach. In this regard, the Fuzzy FMEA approach provides better results in case of vague concepts and imprecise information (Rivera et al., 2009). Moreover, since the conventional FMEA method lacks enough flexibility in reflecting opinion of experts, thus, sufficient flexibility can be achieved by implementing a Fuzzy Expert System (FES) (Chang et al., 2010).

Uncertainty related to occupational accidents has two origins; their randomness due to environmental, natural or time changes (statistical uncertainty), and uncertainty due to relative information (e.g., expert opinion) or dispersion of data (non-statistical uncertainty) (Karimi and Hüllermeier, 2007). However, since often not all past information is accessible for analysis, and considering that in the early stages of the project, there is no feedback from the workshop, therefore, the subjective probability condition should be considered (Xu et al., 2003).

On the other hand, integrating the statistical uncertainty concept to Occupational Risk Assessment (ORA) mainly focuses on monitor and review sub-process of ORA. In conventional ORA (for example section 4.3.1.8 of BS OHSAS 18002:2008), some issues are introduced to affect the timing and frequency of reviews. The following points in brief try to express the practical benefits of integrating statistical uncertainty to the conventional ORA.

- At the time of performing review, the probability of some possible minor changes in the factors affecting safety of jobsite may be clear to the risk management team. These changes may be smaller than activating the review condition of practical standards. However, considering such issues by using the statistical uncertainty concept may lead to more lasting and comprehensive results.
- The holistic approach based on applying this concept may also decrease the frequency of reviews.

To the best of our knowledge, other researchers in the field of occupational safety risk analysis have only considered the non-statistical type of uncertainty. Hence, to complement this research gap, a Fuzzy Probabilistic Expert System (FPES) is presented in this study.

The aim of this paper is to provide an improved system for assessing the risks associated with occupational safety in the construction industry.

To the best of our knowledge, this is the first application of FPES in investigating occupational construction accidents at the international level. Moreover, for the first time, fuzzy probabilistic rules were extracted from association rules and decision trees.

The remainder of this paper is organized as follows: basic concepts of risk assessment related to occupational safety are explained in Section 2. In Section 3, the procedures needed for developing our proposed model are described in detail. System evaluation and validation method and their results are exhibited in Section 4. Finally, conclusions and comments on further research are presented in Section 5.

2. Background

In order to assess the risks associated with occupational safety, different methods have been used so far; within them, FMEA as one of the most common methods of safety risk analysis (Falcone et al., 2013) is examined in detail.

2.1. FMEA method

There are various methods for evaluating and ranking risks. FMEA is one of the risk analysis techniques, which is accepted by international standards. It was first used in 1960 in the field of aerospace engineering for safety analysis. At first, this method was only used in aeronautics, space and nuclear engineering. Then, it was applied widely in the chemical industry and other industries (Ericson, 2005). This method is an effective approach for the prevention of risks and it easily interacts with engineering sciences (Tay and Lim, 2006).

2.2. Conventional FMEA

Failure mode and effects analysis is an engineering technique for defining, identifying, and eliminating known and/or potential failures, problems, and errors from systems, processes or designs (Ardeshir et al., 2015). In conventional FMEA, the degree of criticality of failure modes is determined by calculating Risk Priority Number (RPN). RPN ranges from 1 to 1000 and Severity (S), Occurrence probability (O) and the probability of Detection/control (D) are the factors involved in its calculation. Severity (S) is obtained through potential impacts associated with the failure mode. The occurrence probability of the event (O) is the frequency of failure occurrence. In 2014, Ayyub defined the probability of detection (D) as "a measure of the capability of current controls" (Ayyub, 2014). In the conventional method, a numerical scale ranging from 1 to 10 is used for each of the variables, severity, occurrence probability, and probability of detection. RPN can be calculated by multiplying these values. Failure modes with higher RPN will be more important and higher priority is given to treat them. RPN helps the decision making group to identify and prioritize the sectors and processes that need to be improved or be given an appropriate response. Hence, the detection probability adds more sense to analysis as compared with the conventional product O in S in the risk matrix (Abdelgawad, 2011).

This technique is introduced as one of the most important preventive methods during the process of designing a system (Chin et al., 2009); however, calculating RPN's based on non-fuzzy numbers has been criticized significantly (Chang et al., 2010). This criticism involves the following:

- Different values of S, O, and D may result in somewhat the same risk priority numbers in ranking; but the hidden concept of the risks may be quite different. For example, two different events with the values of 2, 3, 2 and 4, 3, 1, respectively, as S, O, and D will result in an equal RPN (12).
- The relative importance of the parameters S, O, and D is not considered, and it is usually assumed that these three factors are equally important.
- Accurate determination of these factors is difficult because often a lot of scattered information is available for FMEA; hence, it is necessary to use the linguistic terminologies such as low and very high.

2.3. Application of fuzzy theory and ES in FMEA method

Fuzzy logic can be combined with the FMEA method to overcome the shortcomings related to obtaining the value of RPN in the traditional FMEA approach. The fuzzy FMEA approach provides a means by which vague concepts and imprecise information will lead to better results (Rivera et al., 2009). The application of fuzzy theory is useful when the relationship between existing criteria is uncertain or their relationship cannot be stated explicitly.

In 2010, Cheng et al. proposed prioritizing of failures using the fuzzy ranking method. The advantages of such a fuzzy ranking method are: (1) this method reduces the probability of achieving the same risk priority numbers; (2) variables are described as fuzzy membership functions (MFs) causing a more realistic and flexible reflection of practical conditions of the problem; (3) the analysis