



A novel approach to risk assessment for occupational health and safety using Pythagorean fuzzy AHP & fuzzy inference system



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ABSTRACT

Occupational health and safety involves systematic studies aimed at protecting employees from harmful conditions that might be caused by various reasons during the execution of work in the workplace. Different from the literature, in this study, a novel integrated approach, Pythagorean Fuzzy Proportional Risk Assessment (PFPRO), including Fine Kinney, Pythagorean fuzzy analytic hierarchy process, and a fuzzy inference system is used for risk assessment in the field of occupational health and safety. The main difference of the proposed approach is the integration of these methods in a way providing a more accurate risk assessment. The risks of an excavation process in a construction yard are assessed by the proposed method. The results are compared with Pythagorean Fuzzy Failure Modes and Effects Analysis (PF-FMEA) and it is revealed that the proposed method produces reliable and informative outcomes better representing the vagueness of decision making process.

1. Introduction

Risk analysis is the utilization of the available information systematically to determine hazards whereas risk evaluation involves judgments on the tolerability of the risk with respect to some criteria. The whole process of risk analysis and risk evaluation is called risk assessment (Rausand, 2013). Risk assessment techniques are divided into two groups as quantitative and qualitative with respect to the type of parameters used. Techniques aiming at determining the degree of risk based on purely numerical or statistical methods are called quantitative techniques. The methods using parameters that determine the degree of risk based on observations, categorical evaluations, or non-numerical measurements are called qualitative techniques. For example, if the severity parameter is used to determine the risk degree, the relevant method is a qualitative method. Because there is no severity meter to measure the severity numerically. If a risk assessment technique calculates the risk only based on the probability parameter and the probability value is statistically determined from its past records, it is a quantitative technique. Quantitative risk analysis techniques can also be utilized by using categorical data. In this case, quantitative risk analysis techniques might be called mixed techniques. The list of quantitative and qualitative risk analysis techniques is given in Table 1 (Cebi, 2017).

Occupational health and safety (OHS) is described as anticipation,

recognition, evaluation and control of hazards that could harm the health of workers (Fundamental principles of occupational health and safety, 2017). In other words, OHS involves systematic studies aimed at protecting employees from harmful conditions that might be caused by various reasons during the execution of work in the workplace. The scope of OHS has expanded depending on social, political, economic and technological factors (Fundamental principles of occupational health and safety, 2017). Risk assessment techniques used in the field of OHS generally calculate the risk value depending on the probability and severity factors. Since particularly the severity parameter cannot be measured objectively, it is integrated to the evaluation process with the help of subjective evaluation and categorical data.

Likewise, probability values can be evaluated as categorical given that historical data are not available. Categorical data cannot produce sensitive results in terms of computational accuracy. In the literature, the Analytic Hierarchy Process (AHP) method has been frequently used to evaluate subjective and categorical parameters. In addition, there are several studies in the literature that assess risk for OHS based on the AHP method. However, in the literature, the fuzzy set theory is used to take vagueness and impreciseness of subjective evaluations into account.

In AHP, factors related to a decision making problem are categorized and consequently form a hierarchy. After the hierarchy is built, linguistic terms are employed by experts to make pairwise comparisons.

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Table 1
Risk analysis techniques with respect to type of parameters.

Quantitative risk analysis techniques	Qualitative risk analysis techniques
<ul style="list-style-type: none"> • Fault Tree Analysis • Event Tree Analysis • Cause-Consequence Analysis • Management Oversight and Risk Tree • Dynamic Event Tree Analysis • Bow-Tie Risk Analysis 	<ul style="list-style-type: none"> • Check List • What if? Analysis • Preliminary Risk Analysis • Job Safety Analysis • L Matrix Method • X Matrix Method • 3T Matrix Method • Fine Kinney Method • Hazard and Operability Studies • Failure Modes and Effects Analysis

These linguistic terms are converted to numerical values by using fuzzy sets which are able to handle impreciseness and vagueness of evaluation processes. It is thus possible to say that AHP is quite useful for modelling problems in the absence of certain measures.

In this study, Pythagorean fuzzy AHP method is employed to make risk assessment techniques work more effectively as different from the literature. Pythagorean fuzzy sets, an extension of intuitionistic fuzzy sets, is developed for the purpose of providing more freedom to experts in expressing their opinions about the vagueness and impreciseness of the considered problem. Pythagorean fuzzy sets achieve this purpose because experts do not have to assign membership and non-membership degrees whose sum is at most 1. However, the sum of squares of these degrees must be at most 1. The weights obtained through Pythagorean fuzzy AHP will be used as inputs for severity and probability parameter in risk assessment techniques.

In this study, risk value in terms of OHS will be calculated by using an integrated method. The proposed approach consists of Pythagorean fuzzy AHP, fuzzy inference system, and Fine Kinney method. In the traditional Fine Kinney method, the magnitude of the risk is equal to the scalar multiplication of probability, severity, and frequency parameters which are directly obtained from experts. In the proposed integrated method, probability and severity parameters will be determined by the Pythagorean fuzzy AHP (PFAHP) method. Along with frequency parameter directly obtained from experts, the obtained values for probability and severity parameters will be used as inputs for Fuzzy Inference System (FIS), and it will provide a risk value as an output. Reliability of our integrated method will be discussed by comparing it with the Failure Modes and Effects Analysis (FMEA) method. The FMEA method calculates the risk value based on probability, severity and detectability parameters. Likewise, probability and severity parameters obtained through PFAHP will be used for FMEA.

The rest of this paper is organized as follows: A literature review on the combination of AHP-Fine Kinney, and AHP-FIS is given in Section 2. Fine Kinney method, preliminaries on Pythagorean fuzzy sets, steps of PFAHP, and FIS are examined in Section 3. Application of the proposed method and conclusions are presented in Sections 4 and 5, respectively.

2. Literature review

Fine Kinney method is a useful quantitative technique to estimate risks. In the Fine Kinney method, probability, severity, and frequency are obtained for each identified risk. Probability is the possibility of damage occurring over time whereas frequency refers to the frequency of exposure to hazard. Severity represents the magnitude of the harm or damage to human, workplace and environment if the hazard occurs. Risk score is calculated by multiplying probability, severity and frequency. Then, whether the situation is acceptable or not is assessed (Kinney, 1976). There was no study in the literature using both AHP and Fine Kinney methods until 2017. Gul et al. (2017) utilized a combination of fuzzy AHP, fuzzy VIKOR, and Fine Kinney methods for ballast tank maintenance process. Kokangül et al. (2017) used both Fine

Kinney and AHP methods to assess the risks in a large manufacturing company. Hazards were prioritized through AHP and also evaluated using the Fine Kinney method. The link between the results of these two methods was analyzed to identify the risk class intervals for AHP.

Fang et al. (2003) proposed a framework to select the most appropriate scaffolding for a construction project by using AHP. The considered factors in their study are initial cost, running cost, safety risks, cost variation, speed of installation, efficiency of other trades, project quality, and corporate image. Aminbakhsh et al. (2013) introduced a framework involving cost of safety model and AHP to prioritize safety risks in construction projects. Risks affecting construction safety are divided into three main groups as accident hazard, physical hazard, and chemical hazard. These main groups are further divided into sub-groups as trips & falls, electricity & lighting, fire & explosions, machinery & equipment, vibration, temperature, ventilation, burns, and neurological. Chan et al. (2004) adopted AHP to identify the priority of processes for the Hong Kong construction industry. In this study, AHP structure involves cost implication, development time, expertise required, client requirements, and corporate image. Podgórski (2015) utilized AHP to select the main key performance indicators for assessing operational performance of occupational safety and health system. The criteria used in this study are specific, measurable, achievable, relevant, and time-bound. Zheng et al. (2012) employed AHP to assess the work safety in hot and humid environments. Trapezoidal fuzzy numbers are utilized to deal with uncertainty and imprecision of the data. The main factors used in this study are work, environment, and workers whereas sub-factors are work nature, work intensity, and work duration, temperature, humidity, airflow velocity and heat radiation intensity, seniority structure, safety training and personal protection. Wang et al. (2016) adopted nonlinear fuzzy AHP for risk assessment of a coal mine. Risk factors considered in this study include managerial, environmental, operational, and individual criteria. The logarithmic fuzzy preference programming method is used for the analysis of the data. Guneri et al. (2015) employed fuzzy AHP to select the best risk assessment method in occupational safety operations for small and medium sized enterprises by taking scope, practicality, cost, and sensitivity criteria into consideration. Janackovic et al. (2013) utilized fuzzy AHP to prioritize the main occupational safety indicators of road construction companies. Fera and Macchiaroli (2010) utilized AHP and fire dynamics simulator to evaluate fire safety in tunnels by considering carbon monoxide, oxygen, temperature, and visibility criteria. Fera and Macchiaroli (2010) proposed an interesting novel model including Failure Modes and Effects Criticality Analysis (FMECA), Scenario Based Risk Assessment (SceBRA), Italian standard UNI 7249:2007, and AHP. In their study, occupational risks are prioritized and compared with the results of traditional methods and statistical data from a specific firm and with the national industrial sector.

Topuz and van Gestel (2016) developed an environmental risk assessment approach for the usage of engineered nanoparticles by using both AHP and fuzzy inference method, and the proposed method provides the risk class and its membership degree. Nieto-Morote and Ruz-Vila (2011) used fuzzy AHP and fuzzy inference for construction project risk assessment. In the study of Rodríguez et al. (2016), a new risk assessment method involving fuzzy AHP and FIS was developed. FIS is employed to integrate the groups of risk factors, and then these risk factors are utilized as the evaluation criteria for fuzzy AHP. Yang et al. (2011) used a combination of fuzzy AHP and FIS to prioritize environmental issues in offshore oil and gas operations. In Abdelgawad and Fayek (2010), FIS, fuzzy AHP and FMEA were used for risk management in the construction industry. In the study of Zeng et al. (2007), a risk assessment approach was proposed to handle risks in complicated construction processes. AHP was utilized for the prioritization of risk factors whereas fuzzy based decision making method was adopted for the risk assessment of construction projects. On the other hand, Cebi (2011) applied fuzzy multiplication operation on probability and severity parameters to assess the risks in construction projects. In An et al.

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