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An Occupational Safety Fuzzy Risk Analysis: An Application in a Building Construction Sites

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Abstract

Employers should be creating a safe workplace environment in working life. A safe working environment is one where risks are eliminated or at an acceptable level. Building works is one of the areas where occupational accidents are most intense today. In this study, fuzzy logic is proposed to determine the risk levels with linguistic words in risk analysis, which is the most important step of the occupational health management system in the building works. In the fuzzy risk assessment, the fuzzy model was first proposed and then the risk numbers were calculated. In the research, a risk assessment was carried out using fuzzy logic method in a construction site consisting of ten blocks and twelve-storey apartments belonging to a building company. In the fuzzy risk assessment, the fuzzification of the input data, the creation of the member functions of the input and output values, and the fuzzification processes were done with the help of the fuzzy logic toolbox of the MATLAB software program. The results showed that fuzzy risk analysis is effective and credible for creating a safe building site.

Keywords: Fuzzy Logic, Occupational Safety, Risk Analysis, Building sector.

1. Introduction

At the construction site, there are a lot of occupational safety risks. The metric methods are used to assess the risks of the workers but at the construction sites, there are a lot of uncertain conditions for workers. Occupational safety is a serious problem at construction sites such as industrial areas. For these uncertainties conditions, fuzzy sets are used to define the risk to workers.

There are a few studies on fuzzy risk analysis in the literature. These are given below; Gürcanlı and Müngen[1] proposed a fuzzy risk assessment for the construction site. They made a case study on a tunnel project. Morote and Vila [2] presented a risk assessment methodology based on the fuzzy sets theory and the analytic hierarchy process. They applied the proposed method to the rehabilitation project of a building. Liu et al.[3] presented a comprehensive overview of currently known applications of computing with words in risk assessment. They suggested five categories for risk assessment. These are risk assessment based on fuzzy numbers; fuzzy rule-based risk assessment; fuzzy extension of typical probabilistic risk assessment; sequential linguistic approach to risk assessment.

Lin et al.[4] proposed an integrated quantitative risk assessment method. They employed this method of influence diagram and fuzzy theory to estimate accident probability and to deal with the imprecision inherent to the process of subjective judgment. They made a case study on the construction industry. Shiliang et al.[5] proposed an analytic hierarchy process-fuzzy comprehensive evaluation method for as risk of falling from height for the research object. Zhou et al.[6] used quality function deployment, fuzzy analytic network process, fuzzy failure modes, and effect analysis to identify the types and causes of hazards in the construction industry providing risk assessment values of hazard causes and relevant improvement strategies. They made a case study on a hydroelectric project. Ardeshir et al. [7], in water conveyance tunnels, they applied an analytical hierarchy process to estimate the importance of each criterion and calculate the significance of the overall impact of the risk. Debnath et al.[8] developed a Takagi-Sugeno type fuzzy inference system for assessing occupational risks in construction sites. They used an analytical hierarchy process for evaluating the safety levels of each type of injury-prone body part. Seker and Zavadskas [9] used the Fuzzy Decision Making Trial and Evaluation Laboratory (DEMATEL) method by a cause–effect diagram on construction sites for analyzing occupational risks. Also, they made a sensitivity analysis. Amiri et al. [10] proposed a fuzzy probability model based on fuzzy risk-based statistical data mining analyzes of accident databases, together with a detailed literature review. They tested the model on four construction case studies. Biswas and Zaman [11] proposed a methodology for construction project risk assessment under epistemic uncertainty. Their methodology used a triangular fuzzy numbering system to compute risk value by combining expert's opinions and insufficient historical data. Also, they used VIKOR method for risk ranking. They applied their proposed a project of a building and a rehabilitation project of a building. Sadeghi et al.[12] developed an Ensemble Predictive Safety Risk Assessment Model based on the integration of neural networks with fuzzy inference systems. Then, they applied this model which they developed to several Malaysian construction case projects. Topal et al.[13] applied the risk assessment model for small-scale construction sites. In their work, they used the insights of safety experts, checklists for the likelihood of accidents, defining safety levels, severity of risk, and safety barriers.

According to the 2020 work accidents and occupational diseases statistics in Turkey, the numbers of deaths due to work accident for all sectors are 1231 persons. Moreover, the numbers of death at building construction sites are 297 persons. Also, the number of death at building construction sites rate is 24.12 % in all sectors in 2020[14]. At present, building construction sites are the most dangerous sector after mining in our country. In this study, a fuzzy risk analysis has been made which has twelve story apartment houses with ten blocks of a building site. The results showed that the fuzzy risk analysis is effective and believable.

The rest of the paper is organized as follows; an occupational safety risk analysis is explained in section 2. In Section 3, the fuzzy risk analysis is defined. The case study is given in Section 4. The results are discussed in Section 5-Conclusion.

2. An Occupational Safety Risk Analysis

Organizations should implement the occupational health and safety system. They should protect their employees, subcontractors, and all persons in the organization against work accidents and occupational diseases. In our and other many countries in the world, implementing this system is a principle in the law. The occupational risks are estimated and the workers should be protected from these risks. Hazard and risk are often used interchangeably but these terms are different from each other. Hazard is defined as a potential source of damage, harm or adverse health effect on something or a person in the work environment under certain conditions. Risk means, the likelihood of a hazard. Risk assessment is the process of identifying hazards, analyzing the risk associated with those hazards, and determining appropriate ways to control the hazard and reduce the risk.

The risk analyses are classified into three categories. These are defined as qualitative, quantitative, and hybrid techniques. In quantitative techniques, the risks are estimated by statistical, simulations, and other mathematical methods. The risks are defined by numerical results but in qualitative techniques, the risks are estimated through judgment, ranking options, and other descriptive analyses. Also, the hybrid technique mixes both quantitative and qualitative [15]. The fuzzy risk analysis is a qualitative method. Some of the methodologies available in the literature for risk analysis are given as follows;

- Failure mode and effects analysis,
- Safety audit,
- Cause-Consequence diagrams,
- Preliminary hazard analysis,
- Kinney method,
- Machine risk assessment,
- Safety function analysis,
- Fault-tree analysis,
- Event-tree analysis,
- Bow-tie,
- Hazard and operability study,
- Job safety analysis,
- Preliminary risk analysis,
- Human error identification,
- Human reliability assessment,
- Deviation analysis,
- Management oversight and risk tree,
- Barrier diagram,
- Risk assessment decision matrix.

The failure mode and effect analysis (FMEA) is a method that is commonly used in occupational safety management. FMEA is a method developed to identify all potential failures in a product or service step by step. The steps of the FMEA are given below;

Step 1. The process is reviewed,
Step 2. The potential effects of failure are listed,
Step 3. The severity rankings are assigned,
*Step4.*The probability of occurrence ranking is assigned,
Step 5. The detection rankings are assigned,
Step 6. The risk priority numbers are calculated,
Step 7. The action plan is developed.

By using FMEA the risk priority number (RPN) is calculated in multiples of three rankings. These are severity ranking (S), probability of occurrence ranking (O), and detection ranking (D). Each ranking is assigned a value in the range from 1 to 5 and the *RPN* is calculated which is shown in Equation 2.1.

$$RPN = S \times O \times D \tag{2.1}$$

A few studies on risk analysis in the literature are; Hong et al.[16] analyzed the risks that would arise when using an earth pressure balanced type tunnel boring machine in underwater tunnel excavation. An event tree analysis was applied to quantify the risks during the preliminary design phase of the tunnel. Anbari et al.[17] conducted 30 interviews with safety and health professionals and risk management personnel working in the construction industry in Oman. They analyzed 151 responses.

3. Fuzzy Risk Analysis

The fuzzy theory based on fuzzy sets was first developed by Zadeh [18]. A crisp set is defined to be either one or zero. To represent the intensity, in their study, Zadeh used a membership function [19].

In the occupational safety system, risk assessment techniques are very important. At the construction sites and industrial areas, the risk analysis problems contain quantitative and qualitative data; for qualitative data, the fuzzy method should be used for the risk analysis problems.

The fuzzy theory has been applied to different areas such as occupational safety risk analysis. In this study, risk priority numbers are calculated using linguistic terms. The inputs, severity, probability of occurrence and detection of the failure are described as linguistic variables. To fuzzify these inputs, the membership functions are used. The fuzzy risk analysis method is given in Figure 1 [1].

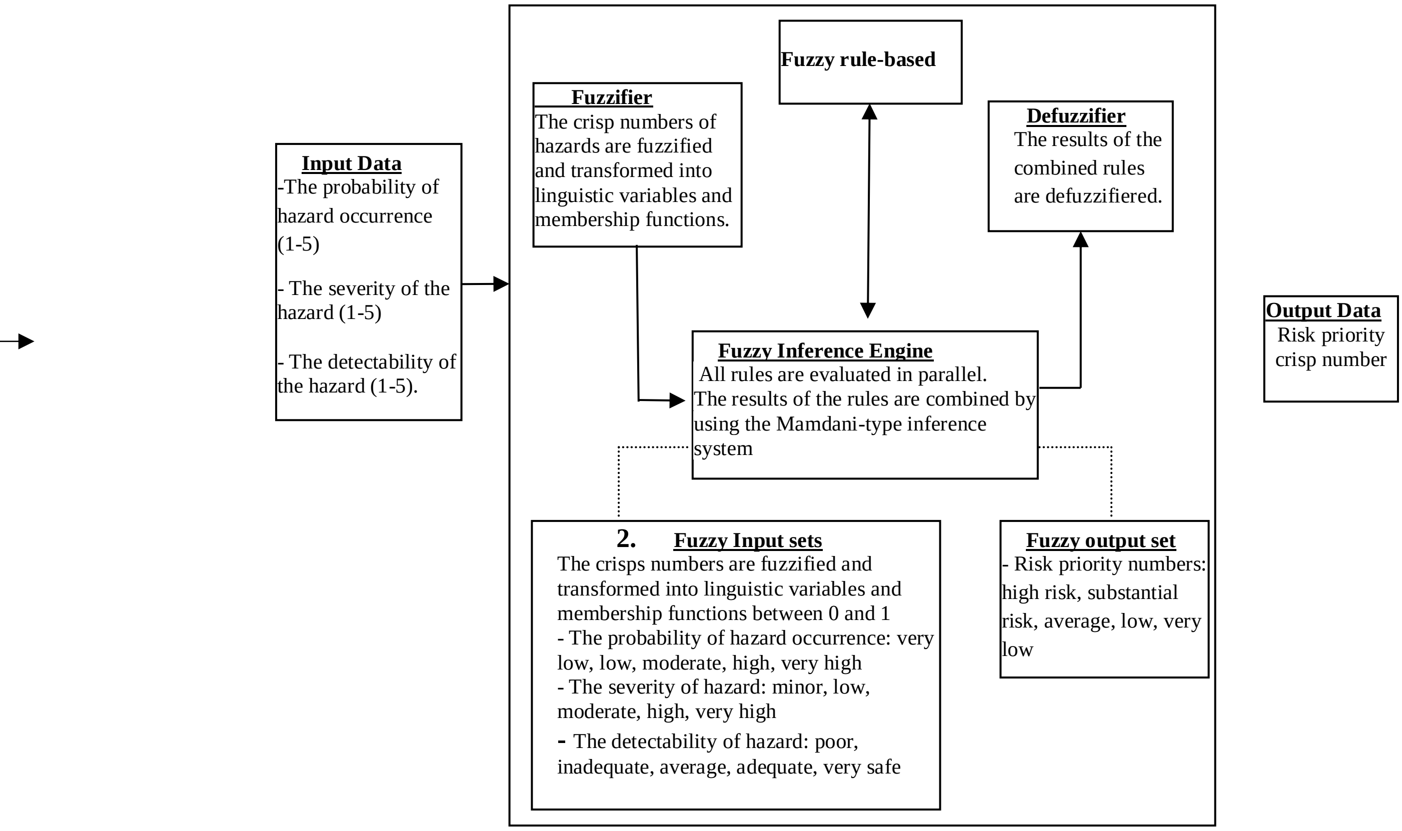

Figure 1. Fuzzy risk analysis model [1].

4. Case Study

At a twelve-story apartment house with ten blocks of building construction sites, risk assessment has been made using fuzzy theory. The activities at the building construction sites are determined by a decision-making group that consists of twenty decision-makers (civil, machine, industrial, electric, and electronic engineers; architecture, chiefs of workers, and workers) from the building construction sites. The twenty-nine activities are determined. Also, the one hundred ninety-eight risks are determined by the decision-making group. The input and output values are defined in the fuzzy set.

The experts assign these parameters as fuzzy variables. The steps of the fuzzy risk analysis and used method are given in Figure 2. MATLAB is used to obtain the results of fuzzy risk analysis. The first step of the risk assessment is to define the input values. In this study, three input variables are used. These are severity, probability of occurrence, and detectability. Each of the input metrics is defined on a scale of rank. The severity scale of rank is given in Table 1.

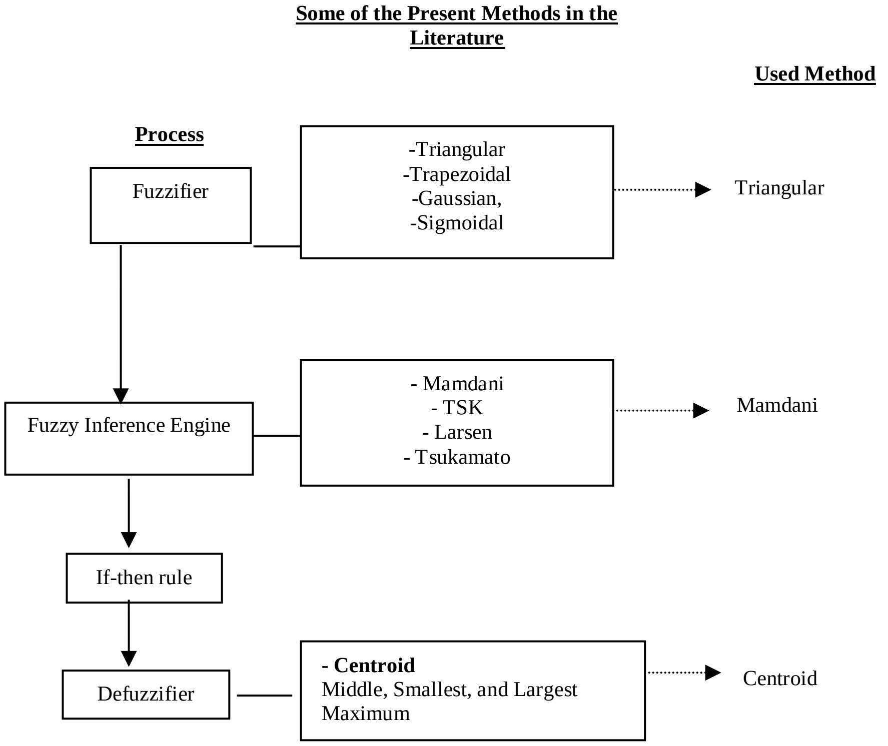

Figure 2. Steps of the Fuzzy risk

Table 1. The severity scale of hazard rank

The severity of the hazard	Linguistic variables	Rank
The danger of death, permanent incapacity	Very High	5
Major injury (Permanent disability, low-loss, occupational disease)	High	4
Requires inpatient treatment, but leaves a lasting impression on accidents that require clinical treatment	Moderate	3
Minor injury (Requiring outpatient)	Low	2
Do not have wounding, a simple accident	Minor	1

The probability of occurrence rank is given in Table 2.

Table 2. The probability of hazard occurrence rank

Probability	Linguistic variables	Rank
Every day (Very high probability)	Very high	5
Once a week (high probability)	High	4
Once a month (moderate probability)	Moderate	3
Once every three months (low probability)	Low	2
Once a year (very low probability)	Very low	1

The detectability scale of rank is given in Table 3.

Table 3. The detectability scale of hazard rank

The detectability of hazard	Linguistic variables	Rank
The measures taken were unavoidable dangers	Poor	5
It is hard to prevent accidents with measures taken	Inadequate	4
The possibility of accident prevention is low with measures taken	Average	3
The possibility of accident prevention is high with measures taken	Adequate	2
The accident is exactly prevented with measures taken	Very safe	1

Then, these three input variables are fuzzified using membership functions provided by experts [20]. The triangular membership function (TMF) is used for the input variables. The fuzzy membership functions (FMF) of the probability of occurrence, severity, and detectability are given in Figure 3-5.

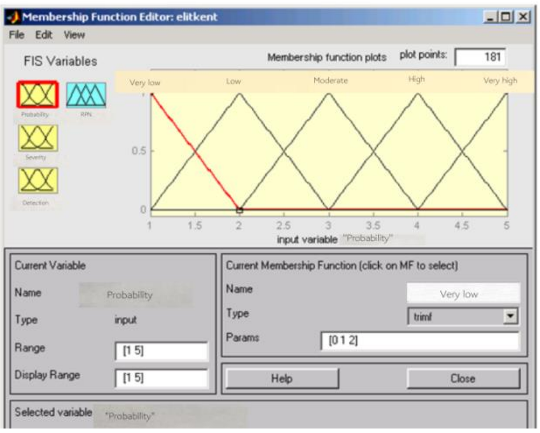

Figure 3. FMF of the probability of occurrence

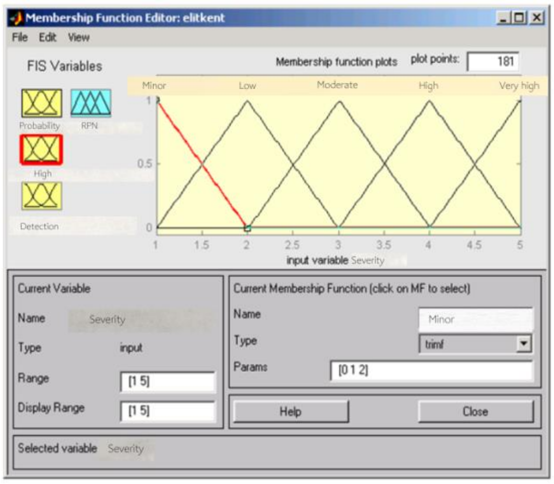

Figure 4. Fuzzy membership functions of severity

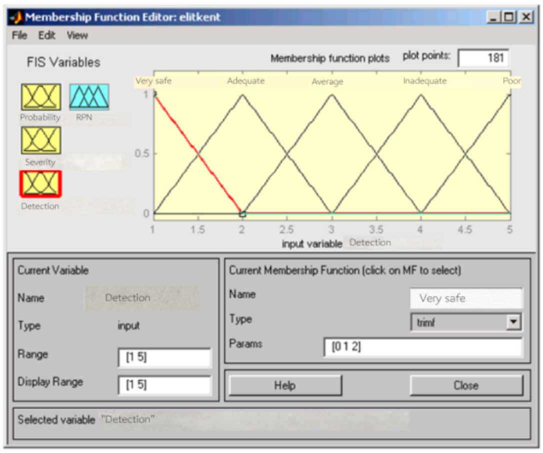

Figure 5. FMF of detectability

Table 4. The fuzzy risk priority number

FRPN	The hazard knowledge	Rank
High Risk	Catastrophic Event: hazard could cause serious injury or death	5
Substantial Risk	Major Event: hazard could cause injury	4
Average Risk	Moderate Event: hazard could cause some problems	3
Low Risk	Minor Event: hazard could cause some minor problem	2
Very Low Risk	Noticeable Event: hazard would not be the noticeable problem.	1

Fuzzy inputs are evaluated using linguistic rule base and fuzzy logic operations. The membership function of the fuzzy risk priority number is given in Figure 6.

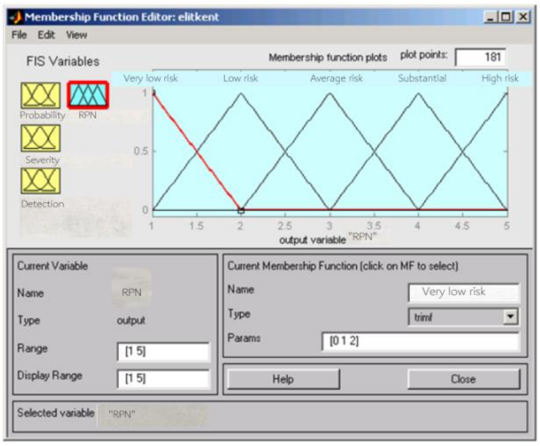

Figure 6. The membership function of the fuzzy risk priority number

In the model, one hundred twenty-five rules were created. The three of these rules are given below as an example.

-If (probability is very low) and (severity is high) and (detectability is very safe) then RPN is substantial risk.
-If (probability is low) and (severity is minor) and (detectability is very safe) then RPN is very low risk.
-If (probability is high) and (severity is minor) and (detectability is very safe) then RPN is very low risk.

The graphical illustrations of these rules are given in Figure 7.

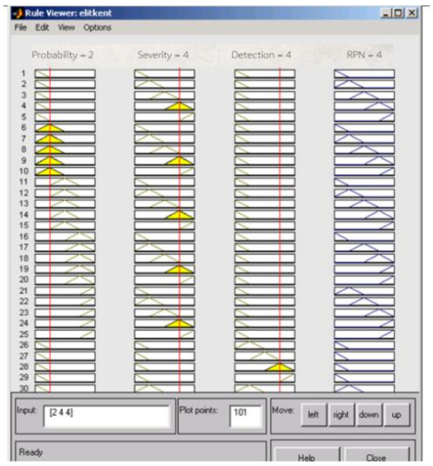

Figure 7. The graphical illustrations of these rules

Figure 7 shows that "Due to the lack of regular loading on the earthmoving truck", The probability 2, severity 4, and detectability 4 for the danger of "overturning the truck" The program output of the RPN value is calculated as 4.

The surface viewer of the output is given in Figure 8.

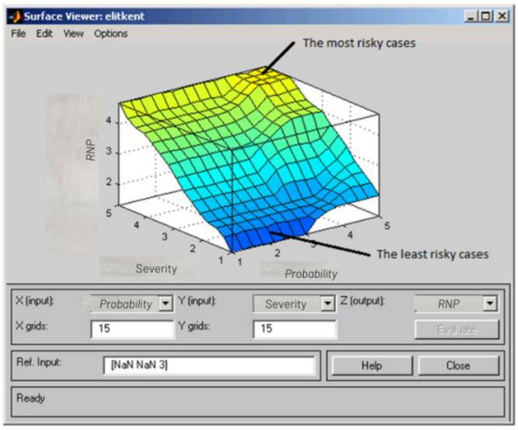

Figure 8.The surface viewer of output

In this study, the RPN determined as a result of fuzzy risk assessment is compared with the data obtained in the FMEA method. For comparing the results, an example is given below.

For example;
During the process of "Preparation of Wooden Mold"

If we make a risk assessment with the FMEA technique for the dangers of "Mold collapse" and "Hand, foot, finger jamming during the mold process", the calculations do as follows.

For the danger of "mold collapse"; the RPN is calculated as follows.

RPN = 2 x 5 x 2 = 20 (Probability 2, Severity 5, detectability 2).

For the danger of "Hand, foot, finger jamming during the mold process" the RPN is calculated as follows.

RPN = 3 x 3 x 3 = 27 (Probability 3, Severity 3, detectability 3).

Whereas, the RPN values for the danger of "mold collapse" should be higher score than the RPN values for the danger of "Hand, foot, finger jamming during the mold process" but with the results of the FMEA technique are found exactly the opposite.

However, as a result of the fuzzy risk assessment made in this study, for the danger of "mold collapse"; the RPN was calculated, 4.68 and for the danger of "Hand, foot, finger jamming during the mold process" the RPN was calculated, 3.

5. Conclusion

In this study, a fuzzy risk analysis method is used at building construction sites, with twelve floors and ten blocks twenty main activities. The activities at the building construction sites are determined by a decision-making group. This group determined one hundred ninety-eight risks at the building construction sites. MATLAB software program fuzzy logic toolbox is used to obtain the results of fuzzy risk analysis. The fuzzy risk priority numbers are evaluated using a linguistic rule base. In the model, three inputs, one output and one hundred twenty-five rules were created. Triangular Membership functions, Mamdani inference and centroid rinsing method were used. When the Risk Priority Numbers determined as a result of fuzzy risk assessment are compared with the data obtained in the FMEA method, it is seen that the fuzzy logic method is more appears to give accurate and logical results. According to the fuzzy risk assessment, some of the most important risks that RPN values were found 4.68 are a man in the excavation pit fall, falling of worker over the mold, mold collapse, an employee falling from scaffold, crane overturn, electric shock, and wall overturn.

Occupational safety risks are very high in construction sites and occupational safety in construction sites is a serious problem in Turkey as well as in the world.

The fuzzy risk analysis is an effective and believable method for preventing job accident and occupational diseases at building construction sites.

For further research, several extensions of ordinary fuzzy sets multi-criteria methodology can be used to prevent job accidents and occupational diseases at building construction sites.

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Author's Contributions

Orhan Engin: Supervision, Methodology, Validation, Writing-original draft, Investigation
Raife Canlar Durmaz: Methodology, Data curation, Writing original draft, Visualization, Investigation, Software.

Ethics
There are no ethical issues after the publication of this manuscript.

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