A FTOPSIS BASED OCCUPATIONAL HEALTH AND SAFETY RISK MANAGEMENT METHOD FOR IDENTIFYING OPTIMAL SAFETY MEASURES FOR BUILDING CONSTRUCTION PROJECTS

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ABSTRACT

A FTOPSIS BASED OCCUPATIONAL HEALTH AND SAFETY RISK MANAGEMENT METHOD FOR IDENTIFYING OPTIMAL SAFETY MEASURES FOR BUILDING CONSTRUCTION PROJECTS

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The construction sector is based mainly on manpower, and it has high injury and death rate when compared to other sectors, particularly in developing countries, because of difficult working conditions, long working hours and lower qualification of workers. According to the research on occupational accidents, it has been found that the health and safety measures for prevention of accidents are always in the best interest of the company and which usually cost much less when compared with the costs of an accident. To reduce or eliminate the potential accidents, especially for work-related accidents, risk analysis needs to be carried out on the safety-related risks and preventive measures need to be taken to reduce the number of accidents before construction phase begins. This will enable contractors to identify and evaluate the risks related to accidents and also decide the safety measures that need to be taken to minimize the risks. The scope of this thesis is to develop a novel qualitative FTOPSIS (Fuzzy Technique of Order Preference Similarity to the Ideal Solution) based occupational health and safety (OHS) risk management method for identifying and evaluating the health and safety risks and also for finding optimal safety measures to minimize the risks for building constructions. A Mixed-Integer Nonlinear Programming Model (MINLP) is included in the method to determine the optimal safety measures for a given budget. To implement the developed risk management method, MS Excel Tool has been created using VBA (Visual Basic for Applications). The method is illustrated by a real case building project.

Keywords: Safety Risk Assessment, Fuzzy TOPSIS, Health and Safety Risk Management, Mixed-Integer Nonlinear Programming, OHS Budget

ÖZ

BİNA İNŞAATI PROJELERİNDE OPTIMAL İŞ GÜVENLİĞİ ÖNLEMLERİNİN BELİRLENMESİNE YÖNELİK FTOPSİS TABANLI İŞ SAĞLIĞI VE GÜVENLİĞİ RİSK YÖNETİMİ METODU

Kılınç, Bora
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İnşaat sektörü ağırlıklı olarak insan gücüne dayanmaktadır ve zorlu çalışma koşulları, uzun çalışma saatleri ve düşük işçi nitelikleri nedeniyle, özellikle gelişmekte olan ülkelerde, diğer sektörlere kıyasla yüksek yaralanma ve ölüm oranlarına sahiptir. İş kazaları ile ilgili araştırmalara göre, kazaları önlemek için iş sağlığı ve güvenliği önlemlerinin her zaman şirketin çıkarlarına olduğu ve bir kazanın maliyetine kıyasla genellikle çok daha az maliyetli olduğu görülmüştür. Potansiyel kazaları azaltmak veya ortadan kaldırmak için, inşaat aşaması başlamadan önce iş sağlığı ve güvenliği (İSG) ile ilgili riskleri ve kazaları önlemek adına alınması gereken önlemler konusunda risk analizi yapılması gerekir. Bu sayede müteahhitler, kazalarla ilgili riskleri tanımlayıp, değerlendirebilir ve ayrıca bu riskleri en aza indirmek için alınması gereken güvenlik önlemlerine karar verebilirler. Bu tezin kapsamı, İSG risklerini tanımlamak, değerlendirmek ve ayrıca bina inşaatı risklerini en aza indirgemek için alınması gereken en uygun İSG önlemlerini bulmak üzere yeni bir FTOPSIS tabanlı nitel İSG risk yönetimi metodu geliştirmektir. Geliştirilen yönteme, belirli bir bütçeye göre en uygun İSG önlemlerini belirleyebilmek için bir Karışık-Tamsayılı Doğrusal Olmayan Programlama Modeli dahil edilmiştir. Geliştirilen risk yönetimi metodunu

uygulamak amacıyla, MS Excel tabanlı bir İSG risk yönetimi aracı oluşturulmuştur. Ayrıca, Geliştirilen yöntem bir bina inşaatında saha çalışması olarak uygulanmıştır.

Anahtar Kelimeler: İş Güvenliği Risk Değerlendirmesi, Bulanık TOPSIS, İş Sağlığı ve Güvenliği Risk Yönetimi, Karma Tamsayılı Doğrusal Olmayan Programlama, İSG Bütçesi

To my beloved family …

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LIST OF ABBREVIATIONS

ABBREVIATIONS

AHP:	Analytical Hierarchy Process
Cc_i:	Closeness Coefficient Index
CPM:	Collective Protective Measures
C:	Consequence
FNIS:	Fuzzy Negative Ideal Solution
FPIS:	Fuzzy positive ideal solution
FTOPSIS:	Fuzzy TOPSIS
HSE:	Health and Safety Executive
L:	Likelihood
MADM:	Multiple Attribute Decision Making
MINLP:	Mixed-integer nonlinear programming model
MODM:	Multiple Objective Decision Making
MCDM:	Multi Criteria Decision Making
OHS:	Occupational Health and Safety
PPE:	Personal protective equipment
TOPSIS:	Technique of Order Preference Similarity to the Ideal Solution
SII:	The Social Insurance Institution
TFNs:	Triangular Fuzzy Numbers
VBA:	Visual Basic for Applications

CHAPTER 1

INTRODUCTION

The construction sector plays a crucial role in the economic development in Turkey as well as other developing countries. The recent technological developments have increased expectations from the construction industry in terms of architectural and cost-efficiency. Therefore, contractors are pushed to build complex architectural structures over limited budget and time, which increases risks taken such as Occupational Health and Safety (OHS).

Despite these technological improvements, the construction sector is based mostly on manpower, and it has a high injury and death rate when compared to other sectors, because of the difficult working conditions, long working hours and lower qualification of workers. It is commonly accepted that the construction industry contains uncertainties within its complex and dynamic nature and workers are at a greater risk at occupational accidents compared to employees in other sectors. Therefore, occupational health and safety which endeavors to preserve the workers' safety and welfare in the construction site is a significant issue in such a human-based industry. Within this scope, taking required OHS measures, investments on accident prevention, legislation and regulations for the protection of workers from the risks of the construction sector is important.

According to research on occupational accidents, it has been found that the cost of health and safety measures to prevent accidents is always in the best interest of the company and it costs much less when compared to the costs of accident (Cıngıllıoğlu, 2012). Also, the cost of the accident is not only pecuniary; it also has intangible damages like the pain of the injured workers, the psychological effects on workers families and colleagues. Besides all of these, construction accidents cause to demotivate other workers, delay in construction operations and cause to decrease in both productivity and reputation of the construction company.

Cost of OHS is divided into two main categories, which are costs of accident prevention and costs of accident (direct and indirect). Accident prevention costs are the costs of application of necessary safety measures to ensure OHS standards related to safety regulations and legislation are met. It includes expenses for personal protective equipment (PPE), collective protective measures (CPM), consultancy about OHS, safety training, payments for safety personnel and various facility costs. On the other hand, the costs of accidents are emerging costs after an accident happens. They are divided into two main categories as direct and indirect cost according to their quality and quantity.

Health-related payments like insurance payments, hospital and medical charges, machinery cost (loss of machinery or repair costs), repeated initial training and managerial costs and monetary losses due to time and production loss during employment of the new staff are some of direct costs of accidents. On the other hand, replacement of the ill or injured worker, the training and adjustment period of the new worker, morale effect of the accidents between workers, damaged public relations and reduction in brand and project value are some of the indirect cost of accident.

To reduce or eliminate the cost of accident and especially work-related accidents, a risk management study needs to be done about cost of accident prevention before construction phase begins. By doing so, contractors can make predictions about total cost of accident prevention and decide which safety measures need to be taken and why. Making this study also requires risks to be identified and evaluated because it is not possible to determine the safety measures without evaluating and ranking safety risks. But usually contractors prefer to do this study during the construction phase, or sometimes never do because they do not want to spend their limited time and resources for such a work. However, before the construction phase, contractors are able to reduce or eliminate work-related accidents by making risk assessment and taking health and safety precautions according to these assessments. So, the most important purpose of this thesis is to make the safety risk management which also involves finding total optimal budget for OHS expenses, which is easily realizable by contractors at every stage of the construction process, especially before construction phase.

Risk assessment is defined by Turkish OHS Law (Law No.6331, 2012) as activities required for identifying hazards which are existing in or may arise from outside the workplace, analyzing and rating the factors causing these hazards to turn into risks and the risks caused by hazards and determining control measures. So, risk assessment is a basic and important tool for both employees and employers to extensively understand how to cope with identified hazards and determine safety measures with classifying and prioritizing different risk items in the workplace within the boundaries of legal regulations and legislation.

The importance of legal regulations and legislation about OHS for protecting employees from various safety risks and hazards by ensuring a safer work environment cannot be denied. Therefore, in Turkey as well as all other countries, legal legislation and regulations have been put in place, in order to provide and maintain OHS standards on construction process. In Turkey, the latest version of OHS law no.6331 was prepared by the Ministry of Labor and Social Security and published in the Official Gazette dated 30 June 2012, numbered 28339. One of the important items that come into force with this law is that the employers are obliged to perform a risk assessment regardless of their activity, size, or structure.

According to the Health and Safety Executive (HSE) risk assessment is based on five basic steps (Neathey et al. 2006) as follows:

- Hazard identification
- Hazard impact analysis
- Risk evaluation and mitigation
- Recording and implementation
- Assessment review

Risk assessment can be carried out quantitatively or qualitatively, but in construction projects, safety professionals mostly prefer and use qualitative safety risk assessment as a tool, because of the complex, dynamic and unique nature of construction process. Risk assessment in construction projects contain lots of subjectivity due to the level of knowledge and experience of safety professionals about risks in construction and their likelihood and consequences. Determination of both likelihood and consequence of hazard is very important and forms the basis of risk assessment because magnitude of a risk is calculated by using Eq.1.1.

$$\text{Risk} = \text{Likelihood (Probability)} \times \text{Consequence (Severity)} \qquad (1.1)$$

Safety professionals use subjective linguistic terms and numerical scales for assessing risks instead of definite judgments. Also, safety professionals have different risk acceptance criteria, and there is no defined acceptable risk acceptance criterion in any legal legislation and regulation. Therefore, for different projects, risk acceptance levels can be different according to unique nature of construction projects and risk assessments are also unique for the project to which it is implemented.

The scope of this thesis is to develop a novel qualitative OHS risk management method for finding the optimal safety measures within a given budget for building construction by using FTOPSIS. Proposed OHS risk management method is based on qualitative data that comes from subjective safety expert judgements as linguistic variables. Fuzzy TOPSIS method was adapted and integrated into this method to cope with subjectivity and uncertainty of safety expert judgments. With the help of fuzzy theory, linguistic variables are translated into numerical values as likelihood and consequence of the identified risk. Then, with the help of FTOPSIS, determined risks are evaluated and ranked according to these fuzzy numbers and methodology of FTOPSIS. The proposed method also determines optimal safety measures for a given budget that are based on risk assessment by developing a mixed-integer nonlinear programming model (MINLP) that can minimize the initial risk value.

In the proposed safety risk management method, Fuzzy TOPSIS (Technique of Order Preference Similarity to the Ideal Solution) is used to perform a risk assessment as the Multi-Criteria Decision Making Model (MCDM). MCDM is associated with choosing the best alternative from a variety of choices created by complex and usually conflicting criteria. Therefore, MCDM was integrated into proposed safety risk management method because most of the construction phase and construction activities are formed by complex situations and processes involving a variety of factors to consider. TOPSIS is a deterministic method, and its evaluation process involves clearly defined data and crisp values. The fuzzy TOPSIS method which was, firstly introduced by Chen (2000) is the extended version of the classical TOPSIS method to adapt real-life decision-making problems where crisp values become insufficient, because of real life's uncertain, unclear and subjective nature. In fuzzy TOPSIS the importance weights of various criterions are considered as linguistic variables, and these linguistic variables are represented by fuzzy numbers to address uncertain, unclear, and subjective nature of classical TOPSIS.

The proposed safety risk management method aims to;

- Determine OHS risk items.
- Determine initial OHS risk index and risk ranking without any safety measures taken with the help of fuzzy TOPSIS.
- Determine OHS measures to mitigate risk ratings by fulfilling legal legislations and regulations.
- Determine minimum OHS risk index and risk ranking that may occur after determining all OHS measures to be taken and the risk mitigation rates of these measures on determined OHS risk items.
- Determine a minimum and maximum budget by finding the cost of these determined OHS measures and expenses.
- Determine the optimal safety measures that can minimize the initial risk index under the existing budget constraint with accordance to at least OHS law no.6331.
- Determine the final OHS risk index and risk ranking according to optimal safety measures determined with the given budget.

To implement the proposed method and to reach the users, MS Excel Tool has been created using VBA (Visual Basic for Applications) which includes a list of construction OHS risks in buildings and OHS expenses.

The proposed MS Excel Tool aims to;

- Make proposed risk management method easily applicable and user friendly.
- Make the mathematical calculations of FTOPSIS method easily applicable for proposed risk assessment process.
- Present all the data that the developed method aims to determine with a simple user interface.
- Integrate proposed mixed-integer nonlinear programming model into risk management process automatically.

- Guide users to perform proposed safety risk management method in the order it should be.
- Reach users of all construction companies from the smallest to the largest enterprise.

OHS law no.6331 force employers to perform a risk assessment regardless of their activity, size or structure but does not recommend any risk assessment method. So, it is believed that the proposed safety risk management method will be useful for contractors in the construction sector.

A case study will be presented to illustrate the benefits of the proposed methodology and The State Hydraulic Works Directorate's New HQ Building Project is chosen for this case study.

In this thesis, the chapters are organized as follows;

In Chapter 2, a literature review is carried out on Occupational Health and Safety (OHS) risk assessment, application of Fuzzy theory in risk assessment and OHS costs.

In Chapter 3, at first, the concept of occupational health and safety (OHS) is introduced. After that general information about OHS costs is given. Then, general information about the OHS law no.6331 and other regulations in force in Turkey are stated. Finally, different OHS Statistics by years in Turkey are mentioned according to The Social Insurance Institution (SII) archive.

In Chapter 4, firstly, the concept of risk assessment is introduced. After that, different types of risk assessments methods are explained. Then determined risk assessment steps and the benefits of performing risk assessment are mentioned respectively.

In Chapter 5, first of all, the concept of Multi-Criteria Decision Making (MCDM) is mentioned, and the classification of MCDM methods is described. Then, Technique of Order Preference Similarity to the Ideal Solution (TOPSIS) is explained. After that, Fuzzy Methodology, Fuzzy TOPSIS and its mathematical steps are described. Finally, FTOPSIS is compared with Fuzzy Analytical Hierarchy Process (AHP), and some of the advantages of using the FTOPSIS instead of FAHP for this thesis are explained respectively.

In Chapter 6, the methodology of developed qualitative OHS risk management method for finding optimal safety measures within a given budget for building construction by using FTOPSIS is explained. In this context, at first, the developed method is described briefly. Then, contributions of the developed risk management method to the literature are stated. After that, the Flow chart and the main steps of the developed risk management method are explained, respectively. The developed mixed integer nonlinear programming model (MINLP) in order to determine optimal cost items that can minimize the initial risk value under the existing budget constraint is also explained in this chapter.

In Chapter 7, the developed Excel tool for implementing the proposed safety risk management method is described in detail. Detailed information about user interface and application of the developed excel tool is explained with screenshots taken from developed tool.

In Chapter 8, the case study implemented in The State Hydraulic Works Directorate New HQ Building Project and its results are described.

In Chapter 9, the main contributions from this thesis for both literature, construction companies and OHS are described. Also, recommendations for future studies are stated.

CHAPTER 2

LITERATURE REVIEW

In this chapter, a literature review is carried out on Occupational Health and Safety (OHS) risk assessment, application of Fuzzy theory in risk assessment and OHS costs. According to the literature review, it is aimed to determine the gaps in the literature and determine the research that needs to be done to eliminate these gaps.

Forteza et al. (2016) developed a new “construction site risk” method which considers different individual risks in the construction site as a whole. According to the author, construction sites have a unique nature, and none of them is the same. Because of that reason, the risks involved are also different from each other. The author also claims that risk assessment tools in literature do not contain this unique nature of the construction environment and only focus on commonly identified risk for all site during the risk assessment process. To close this gap in the literature, a new Construction Site Risk Assessment Tool (CONSRAT) is developed. Within this scope Aneziris et al. (2012) developed a risk assessment model under the Workgroup Occupational Risk Model project (WORM) in the Netherlands based on the Occupational Risk Model (ORCA). The developed method is for building construction projects and contains detailed calculation about risks of fatality and various injuries for all job position. Also, it contains 347 risk reduction measures for specified 63 hazards in its database to increase the reality of this method.

Gündüz and Laitinen (2018) developed a new risk assessment method based on 3T Risk assessment and named as “3TRA-CON”. In this method, for easier implementation and accuracy in risk scores, the conventional definition of probabilities has been replaced with control levels. The author claims that small and medium enterprises are more likely to faced risk because lots of them are not familiar with the risk assessment process and they are lack qualification to perform risk assessment. Because of that reason, the main objectives of this method are to be user-friendly, updatable and useable for all enterprises in every stage of construction period. Also, years before this study to facilitate the risk assessment process, Jannadi and Almishari (2003) developed a Risk Assessor Model (RAM) for construction projects to determine the risk of the construction process and proposed solutions for these risks with quantitative rationale factor. The proposed method specifies risk levels for construction risks and ensures a level of acceptance for these risks. Also, it was transferred to real life as a computer program for safety experts.

Fung et al. (2010) claim that safety professionals stick to their own experience and knowledge during the risk assessment process. Therefore, the risk assessment and the lack of safety approach become subjective. Because of that reason, it is hard to make a sensitivity analysis to determine if the results are reliable or not. To close this gap in risk assessment process, a new Quantitative Risk Assessment Model (QRAM) was developed which based on historical accident data for assessing safety risk ratings during construction process by considering different work item. On the other hand, Pinto (2014) developed a novel qualitative OHS risk assessment model for construction projects by using fuzzy set theory. In this method, the risk level is calculated with four risk parameters called safety climate, severity factors, possibility factors and safety barriers. This method based on subjective expert judgments rather than historical accident data. So, to cope with this indefinite subjectivity fuzzy set theory was used to increase accuracy.

Gürcanlı and Müngen (2009) proposed an OHS risk assessment method for construction projects using the fuzzy set theory to incorporate both historical data and subjective expert judgments. In this method, the risk level is calculated with three parameters called likelihood, current safety level and severity. By this way, the proposed method combines qualitative and quantitative information. Sansakorn and An (2015) also developed an OHS risk assessment method by using fuzzy reasoning technique based on fuzzy set theory to evaluate both quantitative and qualitative OHS risk variables. In this method, in addition to likelihood and consequence, the third parameter of probability of consequence (PC) was added to the determination of risk level to become increase accuracy. The developed method is for building construction projects, and aim is to perform a more reliable and accurate risk assessment process. In this content, Samantra et al. (2017) proposed a new fuzzy-based risk assessment method for metropolitan construction process. In this method, qualitative data and subjective expert judgments were used to determine risk levels rather than historical accident data with the help of fuzzy set theory.

Also, Gürcanlı and Müngen (2006) proposed a fuzzy rule based OHS risk assessment model to deal with subjectivity and uncertainty of the construction process. In this method, both historical accident data and safety professional's subjective judgments are combined to increase the accuracy of the proposed model. Fuzzy Analytical Hierarchy Process (FAHP) and pairwise comparison methods were used for risk evaluation process. In addition, there are other risk assessment methods based on AHP in the literature. Aminbakhsh et al. (2013) used the analytic hierarchy process (AHP) and the theory of cost of safety (COS) model to perform a risk assessment as well as to create a rational safety budget. The proposed method aims to ensure safer working environment by taking enough safety measures within predetermined budget. Ilbahar et al. (2018) developed a new and combined OHS risk assessment method called Pythagorean Fuzzy Proportional Risk Assessment (PFPRA) by using Fine Kinney method, Pythagorean fuzzy analytic hierarchy process (AHP) and a fuzzy inference system. The main aim of this method is to increase the accuracy and reliability of risk assessment process with the integration of these methods.

Liu and Tsai (2012) developed a semi-quantitative risk assessment method for construction projects by using two-stage quality function deployment (QFD) tables to show dealings with risk types and their causes. In this method, to overcome subjective and unstable expert judgments in the risk assessment process, the fuzzy set theory was used. A fuzzy analytic network process (FANP) method was used, and Failure modes and effect analysis (FMEA) was conducted for evaluating specified construction risks.

Mahdevari et al. (2014) developed an OHS risk assessment method for underground coal mines to manage health and safety risks by using fuzzy TOPSIS. The aim of this study is to cope with the vague and imprecise data and subjectivity in expert judgement with the help of fuzzy TOPSIS. In this content, Koulinas et al. (2019) proposed an OHS risk assessment method for sustainable Engineering Projects by using FTOPSIS for ranking defined risks. This is a quantitative risk analysis method that is based on the proportional risk assessment technique (PRAT) and historical accident data.

Moreover, there are risk assessment methods based on hybrid MDCM techniques in the literature. Taylan et al. (2014) developed a method for construction project selection and risk assessment by using the relative importance index (RII) method for prioritizing defined project risks. Then, construction projects are categorized by fuzzy AHP and fuzzy TOPSIS to deal with uncertainty and vagueness in the risk assessment process. Fuzzy AHP was used to create favourable weights of risk variables, and the fuzzy TOPSIS method was used to rank these weighted risks. The aim of the proposed method is to assess the construction projects and their overall risks where vagueness and uncertainty arise. Yazdi (2018) developed a risk assessment method by using the intuitionistic fuzzy hybrid TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) model to cope with both uncertain nature of construction process and subjectivity of expert judgments. For this reason, first, the safety professionals were weighted by using the AHP technique and then, according to the weighted judgments of safety experts, risks are evaluated by using fuzzy TOPSIS. Gül and Ak (2018) proposed a new method for quantifying risk ratings in OHS risk assessment. In this method, the first risk level is found by using 5×5 risk matrix according to the likelihood and consequence of the accident which consists of subjective judgments of safety experts. After that, Pythagorean fuzzy analytic hierarchy process (PFAHP) is used to determine weights for these risks and then fuzzy technique for order preference by similarity to ideal solution (FTOPSIS) is used to rank these weighted risks.

Gül et al. (2017) developed a novel OHS risk assessment method by using a two-stage fuzzy multi-criteria approach. In this method, the risk level is calculated with five parameters which are called, severity, occurrence, undetectability, and sensitivity to maintenance non-execution and sensitivity to personal protective equipment (PPE) non-utilization. Fuzzy Analytic Hierarchy Process (FAHP) is used for weighing these parameters, and then the fuzzy VIKOR (FVIKOR) is used to rank definite safety risks.

Some researchers had also conducted research on both estimating total OHS costs and safety risk assessment in construction projects. Gürcanlı et al. (2015) proposed a method to estimate total OHS costs at the beginning stage of the bidding period by using safety measurements from risk assessment and construction project schedule according to the construction works. In this thesis, Risk assessment performed by using fine-Kinney and L Matrix method. Primavera P6 was used for construction project scheduling. For cost estimation, activity-based methods were used. According to this study, the ratio of safety cost to total construction cost is 1.92%, and 5.68 USD need to be spent for m2 to provide safe work environment according to legal legislations and regulations at 2013. Sousa et al. (2015) developed the Occupational Safety and Health Potential Risk Model (OSH-PRM) for construction projects to estimate the statistical cost of OHS risks and to ease cost-benefit analysis for safety experts. The proposed model ensures to conduct probabilistic cost-benefit analysis according to the construction project schedule by performing a quantitative risk assessment that is based on Monte-Carlo simulation. Bilir and Gürcanlı (2015) revealed a study about safety cost estimation on construction project bidding stage by using risk control measures in OHS risk assessment and construction project scheduling. Safety risk assessment was performed using the L matrix and Fine-Kinney method. Then, Primavera P6 was used for construction project scheduling and finally, activity-based techniques were used for safety cost estimation. To make this study more accurate and reliable, bill of quantities of 25 small or medium scaled building constructions were surveyed. According to this study, the ratio of safety cost to total construction cost is 2.6%, and 9.37 USD need to be spent on m2 to provide safe work environment. Cıngıllıoğlu (2012) revealed a study to determine the relationship between the total cost of OHS expenses and total construction cost. By this purpose, this thesis contains an overview of OHS, safety risk assessment, accident prevention measures and safety cost evaluation process on construction projects.

Additionally, within this scope, some researchers had only conducted research on estimating total OHS costs. Yilmaz and Kanıt (2018) developed a safety cost estimation tool for small or medium-scale building construction projects in accordance with compulsory safety measures. The proposed method contains safety staffing costs, formal safety training courses, PPE, safety facilities and other safety expenses. According to this study, ratio of safety cost to total construction cost is 5.15%, and 8.47 USD is needed to be spent for m2 to provide safe work environment. Elias et al. (2011) developed a quantitative cost-benefit analysis method (QCBA) for guiding the UK construction industry. The proposed method was based on historical OHS accident and cost data and used Benefit-Cost Ratio (BCR) to determine the relation between cost of accident prevention and cost of accident. According to this study, cost of accidents is three times more than cost of accident prevention. Shohet et al. (2018) revealed a study about developing an analytical-empirical model that finds the optimal allocation of OHS measures to determine optimal safety expenses. By this purpose, 30 construction projects in Israel were surveyed, and OHS cost items are determined. Finally, a Monte Carlo simulation was carried out with accordance with surveys to find the total costs of safety depending on the optimal allocation of preventive measures. Korkutan (2010) had revealed a study about, comparison between the OHS costs and total construction cost for building construction by using Dimensionless Quantity and Approximate Cost Estimation Method. Tan (1999) had revealed a study to determine OHS precautions, OHS cost items and total OHS costs based on these. Also, within the scope of this study, the direct and indirect cost of the accident is determined and compared with accident prevention costs.

In addition, some researchers had conducted research on the effects of legal regulations and legislations on total OHS costs in construction projects. Sarıçiçek

(2017) had revealed a study about, determination whether legal regulations and legislations about OHS are properly applied in construction sites, and if they are applied, what is its contribution to total construction costs. In this study, market research method was used to determine cost of OHS measures which are determined by literature reviews and safety experts. Dinç (2014) had performed a study for determining, how obligations in OHS law numbered 6331 in Turkey, effect the OHS costs in house construction. This law specified the minimum precautions and other necessities for OHS.

When the literature about OHS risk assessment and OHS costs were reviewed, it can be concluded that researchers have done many studies on these subjects and the importance of OHS has been accepted by everyone. About OHS risks assessment, researchers generally agree that construction safety risks are uncertain and different for each construction site. Also, these risks are unique which means that, same risks can be at a different level for different construction project. OHS risk assessment is discussed under two main headings as qualitative and quantitative by researcher in literature. However, because of the unique and uncertain nature of the construction safety risks, researchers generally prefer qualitative risk assessments that are based on subjective personal data rather than quantitative risk assessments which is based on historical data. Also, some of them had combined these two methods and used both historical data and subjective expert judgements. To cope with this uncertainty and uniqueness of construction projects, help was taken from linguistic expert judgements. Therefore, researchers developed various new methods based on fuzzy theories to transform linguistic expert judgements into mathematical data. There are lots of safety risk assessment methods in the literature such as qualitative, quantitative and hybrid. Although most of these risk assessments are verified by various studies and surveys, most of them are not user-friendly, contains complex mathematical formulas and based on limited number of safety expert judgement. So, performing these risk assessment methods can be difficult in construction sites that contain limited time and resource. Also, developed methods in the literature can rank and evaluate specified risk according to their risk levels but, they do not specify the total safety risk index and reduction rate. So, decision-makers can face difficulties while determining necessary precautions.

Researchers also mentioned the importance of OHS cost, which can be divided into two main headings as accident prevention cost and accident cost for contractors. There are some studies about OHS cost, but generally, researchers had focused comparison between total safety cost and total construction cost for a limited number of construction projects. Therefore, founded results, rates and statistics about OHS costs are different from each other and depend on the construction projects where surveys conducted. Also, studies for finding total safety costs are generally based on statistics and safety cost items were not specified in detail and clearly. At the same time, these studies are not generally based on construction safety risk assessment so, their effects on total safety risks cannot be determined.

CHAPTER 3

OCCUPATIONAL HEALTH AND SAFETY (OHS)

3.1. General

Being one of the leading parts of the economy of almost all countries, the construction industry generally defined as the driving force of economic growth in developing countries like Turkey. Because of that reason, in developing countries, investments in the construction industry is high, and the construction industry is growing to become dominant in the national economy.

This growth in the construction industry leads to an increase in the number of occupational accidents. İt is commonly accepted that the construction industry contains uncertainties within its complex and dynamic nature. So, all construction projects are unique, even if it is the same project. Also, Construction industry is based mainly on human resources with people skilled, semi-skilled, and unskilled. Therefore, health and safety are significant issues to mind in such a human-based industry, and the necessity of OHS measures, investments on accident prevention, legislation and regulations for the protection of workers from the risks of the construction sector cannot be denied. For these reasons, it is not surprising that work-related accidents have long been causing concern at all points from a single enterprise to a nation.

With increasing awareness of the importance of OHS in the construction sector, there has been an increase in the studies carried out on this issue. But it seems that they are not enough because the construction industry still accounts for a majority of the injuries, both fatal and significant. These injuries can destroy lives and businesses alike, causing machinery and material loss, or even the loss of lives of workers.

Therefore, work accidents can cause financial damage as well as irreversible moral damages.

3.2. Cost of Occupational Health and safety

Due to today's competitive conditions, businesses tend to minimize their costs due to continuity and profitability. These are also valid for the construction industry, and unfortunately, for this reason, contractors try to reduce their costs. Various factors are affecting the total costs, but they think that the cost of occupational health and safety is one of the best ways to save money. Therefore, to become economically competitive during both bidding and construction process and also, to make maximum profit, only some necessary safety precautions and investments are considering, and lots of safety risks are ignored by many contractors. But work accidents can increase the total cost of the project mostly more than the cost of OHS investments by reducing the morale of construction workers, hindering and delaying construction process, reducing productivity and reputation of the construction project.

These accidents and loss of lives have such high costs so that they may affect the enterprise, the nation or even the whole world as a result of its complex aftermath issues like lost working hours, delays, reallocation, and re-hiring. It is such a high value that even one accident may mean the end of business for a small-sized enterprise. In actuality, it is not known how much their accidents cost to the enterprise as there are lots of unknown indirect problems which stem from the accidents. However, it can be said that according to the research and past data, the costs of accident prevention is by ratio approximately 1:3 against the costs of accidents. In other words, when contractors spend 1.00 unit prices on accident prevention, they earn 3.00 unit prices from work accident costs regardless of company and project size (Elias et al. 2011). Considering this information, in addition to much other importance of accident prevention, it is also shown how important it is in financial terms.

3.2.1. Costs of Accident Prevention

Cost of OHS divided into two main categories, which are costs of accident prevention and costs of accident (direct and indirect). The costs of accident prevention are emerging costs before an accident happens.

The costs of accident prevention are:

- Personnel training.
- Personal protective equipment (PPE).
- Collective protective measures (CPM).
- Receive consultancy service on OHS.
- Payments for safety personnel.
- General health and safety expenses like safety facilities.

3.2.2. Costs of Accident

The costs of an accident are emerging costs after an accident happens. They are divided into two main categories as direct and indirect cost according to their quality and quantity. Some of the direct and indirect costs of work-related accidents for the contractor and the owner are shown below.

Some of the direct costs are:

- Health-related payments like insurance payments, hospital, and medical charges, etc.
- Machinery cost (loss of machinery or repair costs).
- Reduction or a temporary halt in the construction process.
- Repeated initial training and managerial Costs.
- Quality loss of the work.
- Monetary losses due to time and production loss during the employment of new staff.
- Legal obligations and litigation costs.

Some of the indirect costs are:

- Replacement of the ill or injured worker.
- The training and adjustment period of the new worker.
- The non-value adding activities like reports and checks.
- Morale effect of the accidents between workers.
- Damaged Public Relations and its effects.
- Reduction in brand and project value.
- Decline in income due to bad reputation.

3.3. OHS Law No.6331

In today's competitive and challenging conditions, the importance and the necessity of legal regulations and legislation about OHS for protecting employees from various safety risks and hazard by creating and maintaining standards for a safer work environment cannot be denied. Therefore, in Turkey, as well as in all other countries, legal legislation and regulations have been put in place, to provide and maintain OHS standards on the construction process.

The concept of occupational health and safety in Turkey formally exist By Labor Law No.4857 that is published in 2003. The purpose of this law is to eliminate or reduce the hazards and risks that employees may face in the workplace. But this law was a recommendation rather than a sanction on the measures have to be taken regarding OHS, and it has been under the initiative of contractors whether the necessary measures are taken or not. Due to these reasons, this law has not received enough attention and become insufficient in terms of OHS. To fill these gaps in the Labor law as a result of long studies, the latest version of OHS law no.6331 was prepared by the Ministry of Labor and Social Security and published in the Official Gazette dated 30 June 2012 and numbered 28339.

3.3.1. Important Items of OHS Law No.6331

To ensure occupational health and safety measures in workplaces and to improve the existing health and safety conditions in the workplaces, Essential items of this law which give certain powers, responsibilities, obligations, and rights to employees and employers are: (OHS Law No.6331, 2012)

- With this law, employers are obliged to perform a risk assessment.
- According to this law, all workplaces are responsible for taking occupational health and safety measures regardless of the area of activity and the number of employees. In other words, according to this law, all employees except military personnel, police, gendarmerie, and undersecretaries of national intelligence service can benefit from the rights of occupational health and safety.
- With Law no.6331, the Joint Health and Safety Units have been established due to the obligation of employers to employ doctors and health personnel in their workplaces regardless of the number of workers. The services provided by occupational health and safety organizations other than the Joint Health and Safety Units should be documented, and necessary notifications should be made.
- It can be said that it is important to record work accidents and occupational diseases in this law. According to this law, the employer is obliged to report the work accidents and occupational diseases in the workplace within three working days. In addition, in case of application to health institutions related to occupational accidents or occupational diseases, the health institution is responsible for notifying the relevant authorities. One of the objectives of this law is to ensure that records of occupational accidents and diseases kept in an effective and healthy manner.
- Occupational health and safety activities should be carried out in coordination, where the enterprises are operating in partnership form more than one

workplace like business centers and industrial sites. This is also the case in subcontracting systems and the case of common use of the same working area.

- With this law, employees have the right not to work or to terminate their contracts if they do not take occupational health and safety measures and not feel comfortable about safety measures in the workplace.
- According to this law, deterrent administrative fines shall be imposed in the case of the determination of practices that are contrary to the administrative sanctions or occupational health and safety law. In cases where the OHS expert and the occupational physician are not employed by the contractor, they must pay 5,000 TL for each employee. If the contractor does not carry out a risk assessment, they must pay 3,000 TL, and in case of inconsistent with law and continuation of the violation, the contractor must pay an administrative fine of 4,500 TL per month. Also, if work accidents and occupational diseases are not reported in the workplace, the contractor is punished with 2,000 TL, and in case of not preparing a major accident prevention policy document, the contractor penalized with an administrative fine of 50,000 TL.

3.3.2. Some Regulations Issued as the Secondary Legislation Related to OHS Law No.6331

Ministry of Labor and Social Security issued a regulation titled "Occupational Health and Safety Regulation on Construction Work" to ensure occupational health and safety in the building area and published in the Official Gazette dated 05.10.2013 and numbered 28786. In this regulation, the minimum occupational health and safety measures which must be taken in construction works are mentioned. Moreover, there are more regulations in the official gazette as the secondary legislation based on OHS law no.6331. Some of these regulations, which are more commonly used in construction safety risk assessment, are shown in Table 3.1.

Table 3.1. Some Regulations in the Official Gazette as the Secondary Legislation Based on OHS Law No.6331.

Name of The Regulation	Release Date	Release No.
Regulation on Occupational Health and Safety Risk Assessment	29.12.2012	28512
Regulation on Occupational Health and Safety Services	29.12.2012	28512
Regulation on Duties, Authority, Responsibility, and Training of Occupational Safety Experts	29.12.2012	28512
Regulation for Occupational Health and Safety Committee	18.01.2013	28532
Regulation on Procedures and Principals of the Occupational Health and Safety Training of the Employees	15.05.2013	28648
Regulation for the Use of Personal Protective Equipment at the Workplace (89/656/EEC, 89/686/EEC)	02.07.2013	28695
Regulation for the Health and Safety Measures to Be Taken in the Buildings and the Extensions of the Workplace (89/654/EEC)	17.07.2013	28710
Regulation for Safety and Health Signs (92/58/EEC)	11.09.2013	28762
Regulation on Prevention of Major Industrial Accidents and Mitigation of Impacts (96/82/EC)	30.12.2013	28867

3.4. Occupational Health and Safety Statistics in Turkey

The Social Insurance Institution (SII) has the widest archives related to work accidents in Turkey. This archive contains overall records of all documented injuries from the criminal court and the labour court from throughout Turkey.

SII publishes comprehensive statistics related to the occupational accidents for the previous year towards the end of each year. The latest one of these statistics published on 10.05.2018 for the year 2017. These annual statistics are helpful to see the current status of OHS but could not adequately reflect the reality about occupational accidents and occupational diseases in Turkey's construction industry because of some reasons. Firstly, the number of unregistered workers in the construction sector is very high. According to the Turkish statistical institute, the rate of unregistered workers in the construction sector is %35.8 in 2017 (SII., 2018). So, it is tough to legally record the number of fatal and non-fatal injuries occurring in the construction sites. Secondly, some contractors are do not report occupational accidents and their consequences to avoid legal responsibilities and sanctions despite being mandated by laws.

For these reasons, in Turkey, it is known that the actual number of data about the occupational accident is much higher than SII statistics in the construction industry. Nevertheless, the construction industry is in first place among other sectors in terms of occupational accidents and diseases according to the annual SII statics. Some of the statistics about the occupational accident, according to SII, are shown below.

3.4.1. Number of Occupational Accidents by Years

The total number of occupational accidents in Turkey shown Figure 3.1, which occurred between 2012 and 2017. It can be easily seen that the total number of occupational accidents is increasing every year and this number is very high when compared with the total number of employees in Turkey. It should also be noted that this number is only officially registered, and it is estimated that the actual number is much more than that. However, when focused on the difference between 2012 and 2013, how the OHS law no.6331, which is become valid in 2013, affects the contractor can easily be seen. The number of total occupational accident is seen to be increased more than twice in 2013 when compared with the year 2012. Because according to this law, the employer is obliged to report the work accidents and occupational diseases in the workplace within three working days.

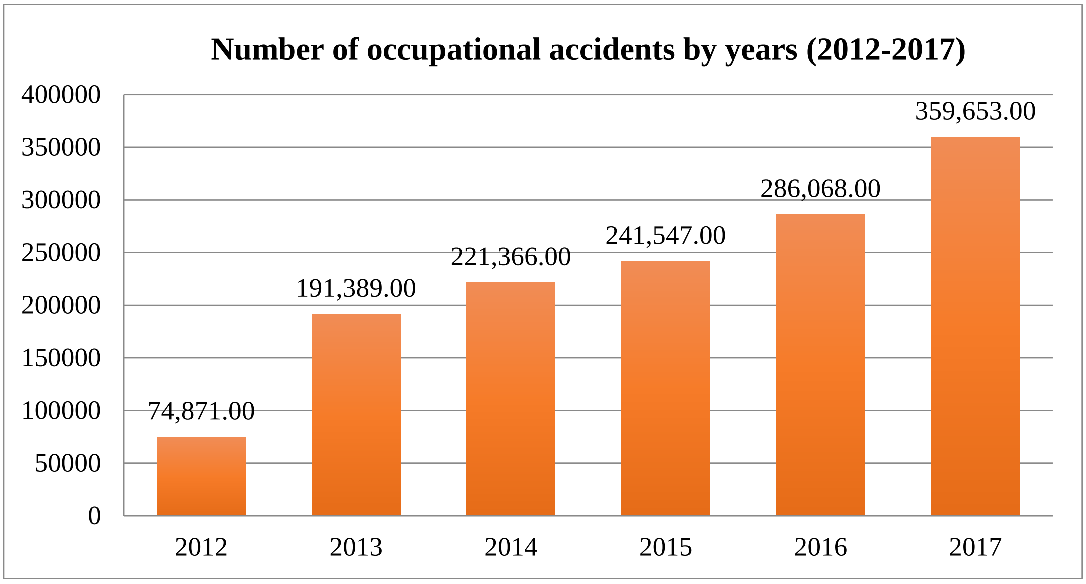


Figure 3.1. Number of Occupational Accidents by Years (2012-2017) (adapted from SII Statistics Reports)

According to Table 3.2. The construction sector, which covers Building Construction, Special Construction Activities, and Construction of other structure ranks first with 44,552 (15.58%) occupational accidents in Turkey.

Table 3.2. Number of Occupational Accidents in 2016 According to Activity Group (adapted from SII Statistics Report 2017)

ACTIVITY GROUP	Number of occupational accident	Percentage (%)
Manufacture of Fabricated Metal Products. (Excluding Machine and Equipment)	20,616	%7.21
Building Construction	20,159	%7.05
Special Construction Activities	14,877	%5.20
Manufacture of Food Products	14,351	%5.02
Manufacture of Textile Products	13,446	%4.70
Main Metal Industry	13,081	%4.57
Food and Beverage Services	12,626	%4.41
Manufacture of other non-metallic minerals	11,721	%4.10
Buildings and Landscaping Activities	11,631	%4.07
Retail Trade (Except Motor Vehicles and Motorcycles)	9,759	%3.41
Motor vehicles, trailers, and semi-trailers manufacturing	9,533	%3.33
Construction of other structure	9,516	%3.33
Storage and Supporting Activities for Transportation	9,496	%3.32
Manufacture of rubber and plastic products	9,258	%3.24
Coal and Lignite mining	8,274	%2.89
Land and Pipeline Transportation	7,246	%2.53
Manufacture of electrical equipment	6,315	%2.21
Manufacture of machinery and equipment not classified elsewhere	6,276	%2.19
Accommodation	5,397	%1.89
Furniture manufacturing	5,013	%1.75
Wholesale trade (Except Motor Vehicles and Motorcycles)	4,835	%1.69
Education	4,744	%1.66
Waste Collection, Treatment and Disposal Activities, Recycling of Material	4,483	%1.57
Human Health Services	4,460	%1.56
Machine and Equipment Installation and Repair	4,277	%1.50
Other Activity Groups	44,678	%15.62
Total	**286,068**	**%100**

3.4.2. Temporary Work Disability Period by Years

Accident costs are divided into two categories as direct and indirect cost and long-time disability, which can occur as a result of the work accident, is one of the most important indirect cost items. Also, long-time disability of worker effects morale and efficiency of both workers and their colleague. In Figure 3.2 the total number of temporary work disability periods according to work accidents is shown between the years 2012 to 2017. It can be easily seen that the total number of temporary work disability period is increasing every year and this number is almost 4 million days in the year 2017 which is extremely high when considering that a year consists of 365 days.

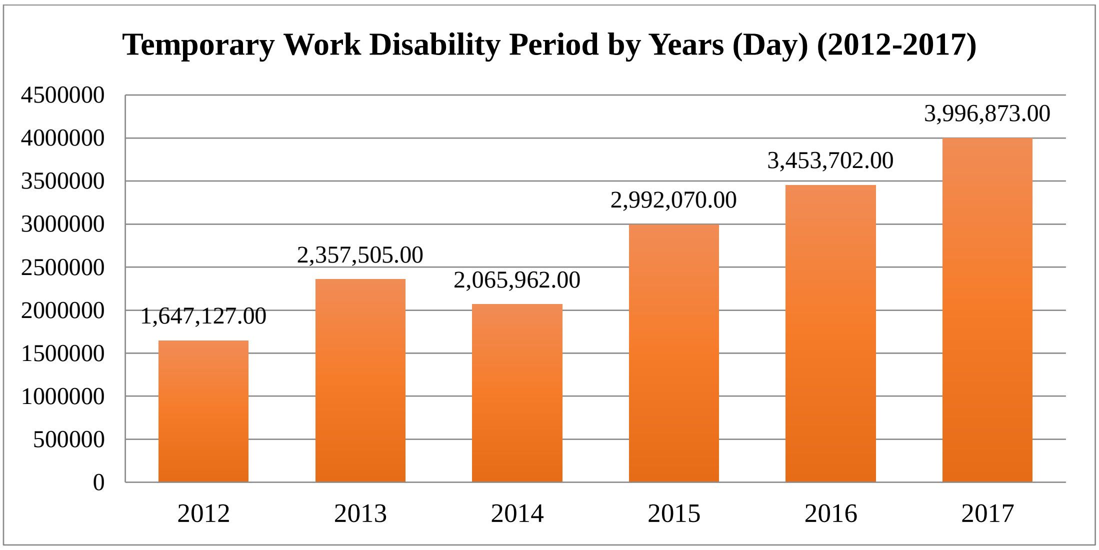


Figure 3.2. Temporary Work Disability Period by Years (Day) (2012-2017) (adapted from SII Statistics Reports)

3.4.3. Number of Fatal Occupational Accidents by Years

The number of fatal occupational accidents shown in Figure 3.3 by years. Because of the obligations of the OHS law no.6331, there is a two-fold increase in the number of the officially registered fatal accidents in the year 2013 compared to 2012. Also, it can be seen that, even if the increase in the number of the fatal accident is not linear, these numbers are very high when considering the importance of the life of a single person.

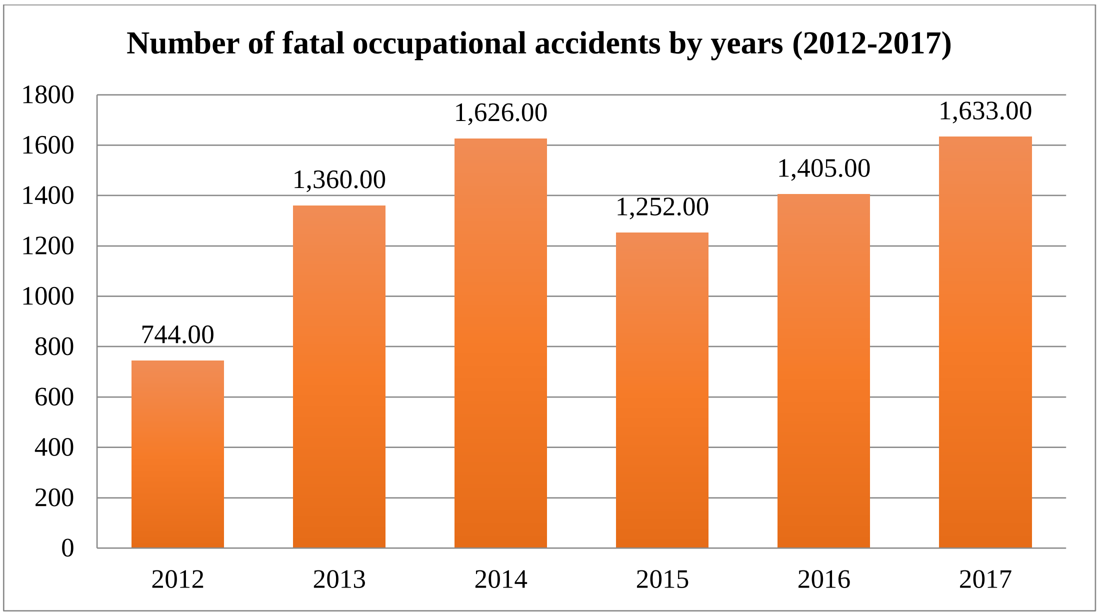


Figure 3.3. Number of Fatal Occupational Accidents by Years (2012-2017) (adapted from SII Statistics Reports)

According to Table 3.3. The construction sector, which covers Building Construction, Special Construction Activities, and Construction of other structure ranks first with 496 (%35.30) fatal occupational accidents in Turkey. This rate is very high and also higher than the total number of occupational accident comparison rate, which shown in Table 3.2. It can be easily seen that work accidents in the construction sector are more dangerous than other industries and more likely to result in death. It should also be noted that this number is only officially registered, and it is estimated that the actual number is much more than that. Considering this situation, the importance of occupational health and safety emerges seriously once again.

Table 3.3. Number of Fatal Occupational Accidents According to Activity Group (adapted from SII Statistics Report 2017)

Activity Group	**Number of fatal occupational accidents**	**Percentage (%)**
Building Construction	239	%17.01
Land Transportation and Pipeline Transportation	179	%12.74
Construction of other structure	130	%9.25
Special Construction Activities	127	%9.04
Other Mining & Quarrying	64	%4.56
Manufacture of other non-metallic minerals	48	%3.42
Wholesale trade (Except Motor Vehicles and Motorcycles)	44	%3.13
Retail Trade (Except Motor Vehicles and Motorcycles)	40	%2.85
Buildings and Landscaping Activities	40	%2.85
Storage and Supporting Activities for Transport	37	%2.63
Manufacture of Food Products	32	%2.28
Main Metal Industry	30	%2.14
Manufacture of Textile Products	27	%1.92
Manufacture of Fabricated Metal Products. (Excluding Machine and Equipment)	27	%1.92
Plant and Animal Production and Hunting and Related Service Activities	19	%1.35
Food and Beverage Services	19	%1.35
Security and Investigation Activities	19	%1.35
Office management. Office Support and Business Support Activities	18	%1.28
Waste Collection, Treatment and Disposal Activities, Recycling of Material	17	%1.21
Machine and Equipment Installation and Repair	16	%1.14
Electricity, Gas, Steam and Ventilation System Production and Distribution	15	%1.07
Accommodation	15	%1.07
Architectural and Engineering Activities, Technical Inspection and Analysis	15	%1.07
Furniture manufacturing	12	%0.85
Coal and Lignite mining	11	%0.78
Other Activity Groups	165	%11.74
Total	**1,405**	**%100**

3.4.4. Total Number of Fatal and Non-Fatal Occupational Accidents in Europe at 2016

The total number of fatal and non-fatal occupational accidents in Europe in 2016 shown in Table 3.4. Germany is at the top with the number of 862,983 non-fatal accidents in Europe, but despite the number of occupational accidents, the ratio of fatal occupational accidents is lower than other countries when a ratio between the number of fatal and non-fatal accidents established. Also, it can be easily seen that Turkey ranks first in Europe with the number of 1,405 fatal occupational accident, even if it is not the first with the number of 286,068 occupational accidents. In Turkey, the ratio between the number of fatal and non-fatal accidents is much higher than in other European countries, although all accidents cannot be officially recorded. Even this shows that Turkey needs to go further in terms of OHS.

Table 3.4. Total Number of Fatal and Non-Fatal Occupational Accidents in Europe at 2016 (adapted from Eurostat Statistics)

Country Name (Alphabetically)	**The Number of Non-fatal Occupational accidents in 2016**	**The Number of Fatal Occupational accidents in 2016**
Austria	62,902	109
Belgium	70,674	64
Bulgaria	2,188	81
Croatia	13,263	33
Cyprus	1,900	5
Czech Republic	45,282	106
Denmark	49,439	34
Estonia	6,354	26
Finland	41,106	35
France	749,670	595
Germany	862,983	413
Greece	3,987	33
Hungary	27,434	83
Iceland	0	0
Ireland	14,088	43
Italy	295,967	481
Latvia	1,810	38
Lithuania	3,541	44
Luxembourg	7,152	22
Malta	1,818	7
Netherlands	81,165	36
Norway	10,150	45
Poland	84,037	243
Portugal	135,033	138
Romania	4,188	236
Slovakia	9,814	45
Slovenia	12,162	14
Spain	432,052	296
Sweden	37,858	37
Switzerland	87,386	79
Turkey	286,068	1,405
United Kingdom	227,165	252
Total	3,668,636	5,078

CHAPTER 4

RISK ASSESSMENT

4.1. General

Risk assessment is defined by HSE (Health and Safety Executive) to analyze what is causing accidents, where and how people get injured in the workplace (Cıngıllıoğlu, 2012). So, occupational health and safety professionals can decide whether they have taken required measures or should take more to reduce or to stop injuries. More generally, Risk assessment is a simple but essential tool for both employees and employers to extensively understand how to cope with identified hazards and determine control measures with the method of classifying and prioritizing different risk items in the workplace.

4.2. Quantitative and Qualitative Risk Assessment

Risk assessment can be carried out quantitatively or qualitatively. While carrying out a quantitative risk assessment, risk value is determined with mathematical formulas by using recorded past data which are collected from different types of projects within different time. On the other hand, in qualitative risk assessment, risk value is determined by subjective numerical scales for assigning likelihood and consequences of these hazards to identified risk, and after that, these are processed by mathematical and logical methods. There are lots of risk assessment methods in the literature, both quantitative and qualitative, and they are shown in Table 4.1 below.

Table 4.1. The List of Quantitative and Qualitative Risk Analysis Techniques (adopted from Ilbahar et al. 2018)

Quantitative Risk Analysis Techniques	**Qualitative Risk Analysis Techniques**
• Fault Tree Analysis	• Check List
• Event Tree Analysis	• What if? Analysis
• Cause-Consequence Analysis	• Preliminary Risk Analysis
• Management Oversight and Risk Tree	• Job Safety Analysis
• Dynamic Event Tree Analysis	• L Matrix Method
• Bow-Tie Risk Analysis	• X Matrix Method
	• 3T Matrix Method
	• Fine Kinney Method
	• Hazard and Operability Studies
	• Failure Modes and Effects Analysis

In construction projects, safety professionals mostly preferred and used qualitative safety risk assessment as a tool, because of the complex, dynamic, and unique nature of the construction process. Risk assessment in construction project contains lots of subjectivity due to the level of knowledge and experience of safety professionals about risks in construction and their likelihood and consequences. Therefore, safety professionals use subjective linguistic terms and numerical scales for assessing risks instead of definite judgments. In quantitative safety risk assessment, using recorded past data which collected from different projects with different condition and type, can lead to inconsistent results on safety risk assessment and may not show an exact situation of hazard analysis (Pinto, 2014). By considering this nature of the construction process, past data from a different project can only be a helpful assistant to give a viewpoint. (Gürcanlı and Müngen, 2009).

4.3. Risk Assessment Steps

According to the HSE, Risk assessment is based on five basic steps (Neathey et al. 2006) as follows:

- Identifying hazards. (**Hazard identification)**
- Determining who could be harmed and how. (**Hazard impact analysis)**
- Risk evaluation and decision making on precautions to mitigate these risks. **(Risk evaluation and mitigation**)
- Recording and implementing emerging Risk data. (**Recording and implementation)**
- Reviewing the risk assessment according to the change of the current situation and update if necessary. (**Assessment review)**

4.3.1. Hazard Identification

Hazard identification is intended to identify potential risks related to any job to be performed by workers.

4.3.2. Hazard Impact Analysis

This part is to determine who or what could be affected or harmed, based according to identified hazards.

4.3.3. Risk Evaluation and Mitigation

The objective of this step is to decide whether a risk is tolerable or not. And if the risk is decided as intolerable, to assess various risk control measures that can be taken to eliminate or mitigate this risk.

Risk evaluation is based on the decision of hazard likelihood and consequence. Likelihood can be defined as how often a hazard will take place and consequence can be defined as a description of how bad and severe the hazard could be. They can be mostly determined by the experience of safety professionals but, historical data can also be used. Determination of both Likelihood and consequence of hazard is very important and forms the basis of risk assessment because risk of hazard is determined by using the following equation (Eq. 4.1).

$$\text{Risk} = \text{Likelihood (Probability)} \times \text{Consequence (Severity)} \qquad (4.1)$$

A control measure to mitigate or remove these risks can be something that includes any tool, procedure or process, and they must be complying with regulations, legislations. Control measures can be divided into two main topics as proactive and reactive. Proactive control measures can eliminate, prevent or reduce the likelihood of hazardous event. On the other hand, reactive control measures can reduce the consequences of hazardous event (Huges and Ferret, 2011).

The main aim of risk evaluation is not to reach a definite number but to provide relative scores to various risks with consequence and likelihood ratings. Thus, the priorities of different risks can be determined, and decisions can be easily made by safety professionals about first, which hazards need to be dealt and what control measures need to be applied. So, risk evaluation is also useful for finding the cost of health and safety.

4.3.4. Recording and Implementation

Risk values achieved during the risk assessment process should be recorded for both in terms of facilitating the work of the occupational safety professionals and legal regulations and legislations. These records need to include both detailed information about any hazards that assessed in the risk assessment, and control measurements are taken to mitigate or remove those risks.

4.3.5. Assessment Review

Risk assessments should be reviewed and renewed when risk conditions change, or a new risk involved in the process. It is also being renewed within a certain period according to the legal regulations and legislations

4.4. The Benefits of Performing Safety Risk Assessment

The benefits of performing a safety risk assessment in the construction project may be the following:

- Reducing the number of work-related injuries in the construction project.
- Reducing time and equipment loss by ensuring the continuity of the construction process.
- Reducing the safety risks in the hazardous environment of the construction project.
- Minimizing insurance costs, medical expenses, legal costs of accident litigation and fines, due to reduction or elimination of the number of accidents.
- Causing enhancement in employee morale and productivity due to a safe working environment.
- Enhancing the brand value of Construction Company and their incomes, due to good reputation about health and safety applications.

It should be noted that carrying out Risk Assessments would not entirely prevent accident, injuries and exceeding of budget during construction process but it will play a decisive role in cutting down their probability of occurrence.

CHAPTER 5

MULTI CRITERIA DECISION MAKING (MCDM)

5.1. General

Multi-criteria decision making (MCDM) is associated with choosing the best alternative from a variety of choices created by complex and usually conflicting criteria. MCDM techniques are helpful tools to aid decision-makers in their choice for a better option when discrete problems are considered.

Decision-making can be defined as finding and choosing an alternative from a set of options based on the preferences of the decision-maker(s). Usually, there are several criteria involved in this finding and choosing process, that’s why these problems are called multi-criteria decision-making problems.

MCDM is widely used in different sectors all around the world by experts such as business, economy, production, etc. Construction is one of the sectors where this decision-making method is used. As most of the construction phases and construction activities are formed by various complex tasks and processes involving a variety of factors to consider. Because of that reason, it will be difficult to make decision in the construction environment. Decisions can be made by providing weights which are determined from managers to different criterions. It is necessary for managers to have enough experience to determine the structure of the problem which is related to the construction project and evaluate multi-criteria.

5.2. Classification of MDCM Models

According to Hwang and Yoon (1981), MCDM problems can be categorized into two groups due to their difference in the criteria evaluation process. They are MADM (Multiple Attribute Decision Making) and MODM (Multiple Objective Decision

Making). MODM involves the optimization of an alternative based on priority objectives. LPP, Goal programming are some of the MODM methods. On the other hand, MADM models can choose the best alternative from a list of alternatives based on their priority attributes. AHP, VIKOR, TOPSIS, ELECTRE are some of the MADM methods.

5.2.1. Technique of Order Preference Similarity to the Ideal Solution (TOPSIS)

TOPSIS is one of the frequently used MCDM method which was first suggested by Hwang and Yoon (1981) and in the following years expanded by Chen and Hwang (1992). TOPSIS is a multi-aspect decision-making method which modifies multi-response values into a single performance criterion value by assigning the best alternative among many feasible alternatives by calculating the distances between the positive ideal solution and the negative ideal solutions. Which means that selected alternative should have the shortest distance from the positive ideal solution (PIS) and the longest distance from the negative ideal solution (NIS).

TOPSIS is a deterministic method, and its evaluation process involves clearly defined data and crisp values. But, while modelling real-life decision-making problem crisp values become insufficient because these problems always contain uncertain, unclear and subjective data. This makes the decision-making process more complicated and compelling (Mahdevari et al. 2014). At the same time, human attitudes and preferences are also generally unclear and subjective. So, it is not possible to estimate them with crisp values. To transforms this qualitative and subjective data into some equivalent quantitative and objective data and also make decision-making process more realistic by considering real-world situations, fuzzy approaches have been used for a long time.

5.2.2. Fuzzy TOPSIS

The fuzzy TOPSIS method which was, firstly, introduced by Chen (2000) is the extended version of the classical TOPSIS method to adapt real-life decision-making problem where crisp values become insufficient, because of real life's uncertain, unclear and subjective nature.

In fuzzy TOPSIS, the importance weights of various criteria are considered as linguistic variables and these linguistic variables are represented by fuzzy numbers to address uncertain, unclear and subjective nature of classical TOPSIS. The fuzzy number belongs to the closed interval 0 and 1, where there is an incremental rate of membership from 0 to 1. On the other hand, there are only 0 or 1 in crisp sets. It means that fuzzy sets are a general version of crisp sets without changing any boundary. There are different types of fuzzy numbers and which one to use depends on the problem structure. But generally, for decision-maker it is always suitable to use Triangular Fuzzy Numbers (TFNs) because it is simple to use in computations and easy to understand. A TFN can be defined as triplet $\widetilde{M} = (l, m, u)$, where l is min value, m is mean value and u is max value shown in Figure 5.1.

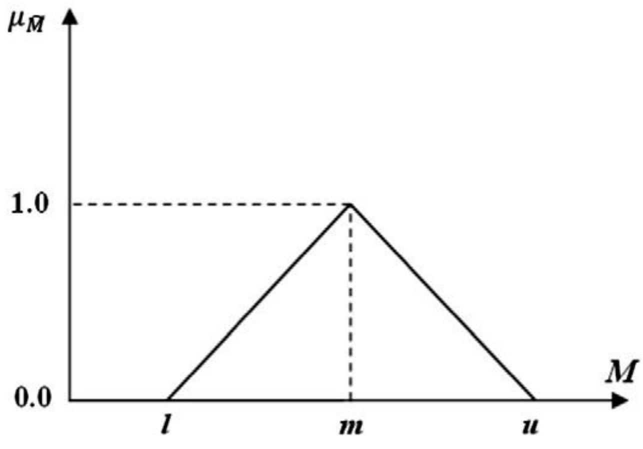


Figure 5.1. Schematic View Of a Triangular Fuzzy Number (adapted from Mahdevari et al. 2014)

$\mu_{\widetilde{M}}(x)$ is the membership function of $\widetilde{M}$ and can be defined as given in Eq. 5.1.

$$\mu_{\widetilde{M}}(x) = \begin{cases} 0, & x < l, \\ \frac{(x-l)}{(m-l)}, & l \leq x \leq m, \\ \frac{(u-x)}{(u-m)}, & m \leq x \leq u, \\ 0, & x > u, \end{cases} \tag{5.1}$$

5.2.2.1. Mathematical Steps of FTOPSIS

The first step of the fuzzy TOPSIS is assessing various criteria according to their likelihood and consequences through the use of linguistic variables after that these linguistic variables are converted into triangular fuzzy numbers according to the predetermined fuzzy scale by experts. Later normalization process has to be done to keep these fuzzy numbers between the range [0,1].

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{u_j^+}, \frac{m_{ij}}{u_j^+}, \frac{u_{ij}}{u_j^+}\right); \; u_j^+ = max\, u_{ij};\; \forall_j^+ \tag{5.2}$$

$$\tilde{r}_{ij} = \left(\frac{l_j^-}{u_{ij}}, \frac{l_j^-}{m_{ij}}, \frac{l_j^-}{l_{ij}}\right); \; l_j^- = min\, l_{ij};\; \forall_j^- \tag{5.3}$$

The normalized fuzzy decision matrix, in case of g alternatives and n criteria, can be obtained as:

$$\tilde{R} = \left[\tilde{r}_{ij}\right]_{nxg} \tag{5.4}$$

Where, $\tilde{r}_{ij}$ refers to the normalized value of $\tilde{x}_{ij} = \left(l_{ij}, m_{ij}, u_{ij}\right)$.

After that, the weighted normalized value $\tilde{v}_{ij}$ can be calculated by multiplying the weights $(\widetilde{w}_j)$ of criteria by the normalized fuzzy decision matrix $\tilde{r}_{ij}$. The weighted normalized decision matrix $\widetilde{V}$ for each criterion can be obtained as:

$$\widetilde{V} = \left[\widetilde{w}_j \tilde{r}_{ij}\right] = \left[\tilde{v}_{ij}\right]_{nxj} \; i = 1,2, \ldots, g \;\; j = 1,2, \ldots, n. \tag{5.5}$$

The next step is obtaining the fuzzy positive ideal solution (FPIS) (A^{+}) and fuzzy negative ideal solution (FNIS) (A^{-}).

$$A^{+} = (\tilde{v}_1^{+}, \tilde{v}_2^{+}, \tilde{v}_3^{+}, \ldots, \tilde{v}_n^{+}) = \{\max v_{ij} | (i = 1,2, \ldots, g; j = 1,2, \ldots, n)\} \tag{5.6}$$

$$A^{-} = (\tilde{v}_1^{-}, \tilde{v}_2^{-}, \tilde{v}_3^{-}, \ldots, \tilde{v}_n^{-}) = \{\min v_{ij} | (i = 1,2, \ldots, g; j = 1,2, \ldots, n)\}. \tag{5.7}$$

After that, the distance of each alternative from the FPIS ($\mathrm{d}_\mathrm{i}^{+}$) and FNIS ($\mathrm{d}_\mathrm{i}^{-}$) are calculated, and the distance between two triangular fuzzy numbers (TFN) is obtained by the vertex method as:

$$d_i^{+} = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^{+}) \tag{5.8}$$

$$d_i^{-} = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^{-}) \tag{5.9}$$

$$d_v(\tilde{g}, \tilde{n}) = \sqrt{\frac{1}{3}[(l_1 - l_2)^2 + (m_1 - m_2)^2 + (u_1 - u_2)^2]} \tag{5.10}$$

Finally, the alternatives can be ranked using closeness coefficient (Cc_i) which is obtained as:

$$C_i = \frac{d_i^{-}}{(d_i^{+} + d_i^{-})} \tag{5.11}$$

$d_i^{+}, d_i^{-} \geq 0$ and $C_i \in [0,1]$

$C_i = 1 \;\; if \;\; A_i = A^{+} \qquad C_i = 0 \;\; if \;\; A_i = A^{-}$

5.3. Advantages of FTOPSIS Against FAHP

During literature research, it was realized that there are many Fuzzy MCDM methods, but Fuzzy TOPSIS and Fuzzy AHP are used significantly more than others about risk assessment. When these two methods are compared with each other, it is observed that they have some advantages and disadvantages. Some advantages of FTOPSIS against FAHP are described below:

- TOPSIS method has simple calculation process so, it is easy to understand and to apply while decision making.
- TOPSIS method follows the same calculation steps for each problem solution without being affected by the excess of criteria by preserving accuracy. On the other hand, AHP uses a hierarchical structure by pairwise comparison. So, when the number of criteria increases, calculation process become longer and more complex. Therefore, accuracy of AHP is reduced when there are too many criteria (Widianta et al. 2018). According to the research of Zanakis et al. (1998), when criteria are added or removed to the decision-making process. It was observed that TOPSIS has the least ranking for instability among other methods.
- Another disadvantage of FAHP is the importance weights of the least important criterion can be equal to zero. Therefore, this criterion is not considered in decision making process. However, there is no such an obstacle in FTOPSIS.

As a result of researches, it is seen that FTOPSIS has more advantages than FAHP to use in safety risk assessment. Therefore, FTOPSIS was selected among many MCDM methods for this thesis.

CHAPTER 6

QUALITATIVE OHS RISK MANAGEMENT METHOD FOR FINDING OPTIMAL SAFETY MEASURES WITH A GIVEN BUDGET FOR BUILDING CONSTRUCTION BY USING FTOPSIS

6.1. General

In this thesis, a novel qualitative OHS risk management method for finding optimal safety measures with a given budget for building construction by using FTOPSIS was developed. Developed OHS risk management method is based on qualitative data that comes from subjective safety expert judgements. These judgements are linguistic variables and contain lots of subjectivity due to the level of knowledge and experience of safety professionals about risks in construction and their likelihood and consequences. Fuzzy TOPSIS method was adapted and integrated into this method to cope with subjectivity and uncertainty of safety expert judgments. With the help of fuzzy theory, linguistic variables were translated into numerical values as likelihood and consequence of the identified risk. Then, with the help of FTOPSIS, determined risks were evaluated and ranked according to these fuzzy numbers. The developed method also aims to find optimal safety measures with a given budget based on risk assessment, in accordance with the OHS law no.6331. The extended list of OHS cost items and measures for building construction were given and minimum universal requirements according to law no.6331 are shown to the user in detail. First, risk reduction rates of these safety measures for both likelihood and consequence are determined by safety experts on a given list. Then, quantities and unit prices of OHS cost items that were given to the user as a list, are found by project drawings, experience of safety experts, number of employees, project information and market research method. After that, with the help of the proposed mixed integer non-linear programming method, optimal safety measures with a given budget is found in order to determine the set cost items that can reduce the initial risk value to the minimum possible value subject to the budget constraint.

6.2. Contributions of the Developed Method to the Literature

To fill the gaps in the literature on OHS risk assessment mentioned earlier, the proposed method is aimed to be as simple as possible to be user-friendly and easily applicable with predetermined building construction safety risks list and FTOPSIS model. A risk index is added to this method with the help of FTOPSIS to guide safety experts in a more accurate and simple way. With the help of FTOPSIS, the number of participant limit in the proposed risk management method set as unlimited in order to increase the number of participant and accuracy of results. The proposed method also makes it easier for the user to update and renew the risk assessment and determine initial and final risk index and ratings.

To fill the gaps in the literature on OHS cost mentioned earlier, based on the predefined list of potential cost items for prevention of OHS risks in building constructions, the proposed method determines the total OHS cost and the optimal safety measures in accordance with a given budget. There is no study in the literature about finding optimal safety measures with the given budget. Also, proposed method gives specific results for different construction projects and determines OHS cost according to the market research method. So, this method is based on real-life data for OHS cost rather than statistics. At the same time, determination of both OHS costs and optimal safety measures are included in the construction safety risk assessment process; therefore, their effects on total safety risks, and their results can be determined. The flowchart of the proposed method is given in Fig. 6.1.

6.3. Flow Chart of the Developed Method

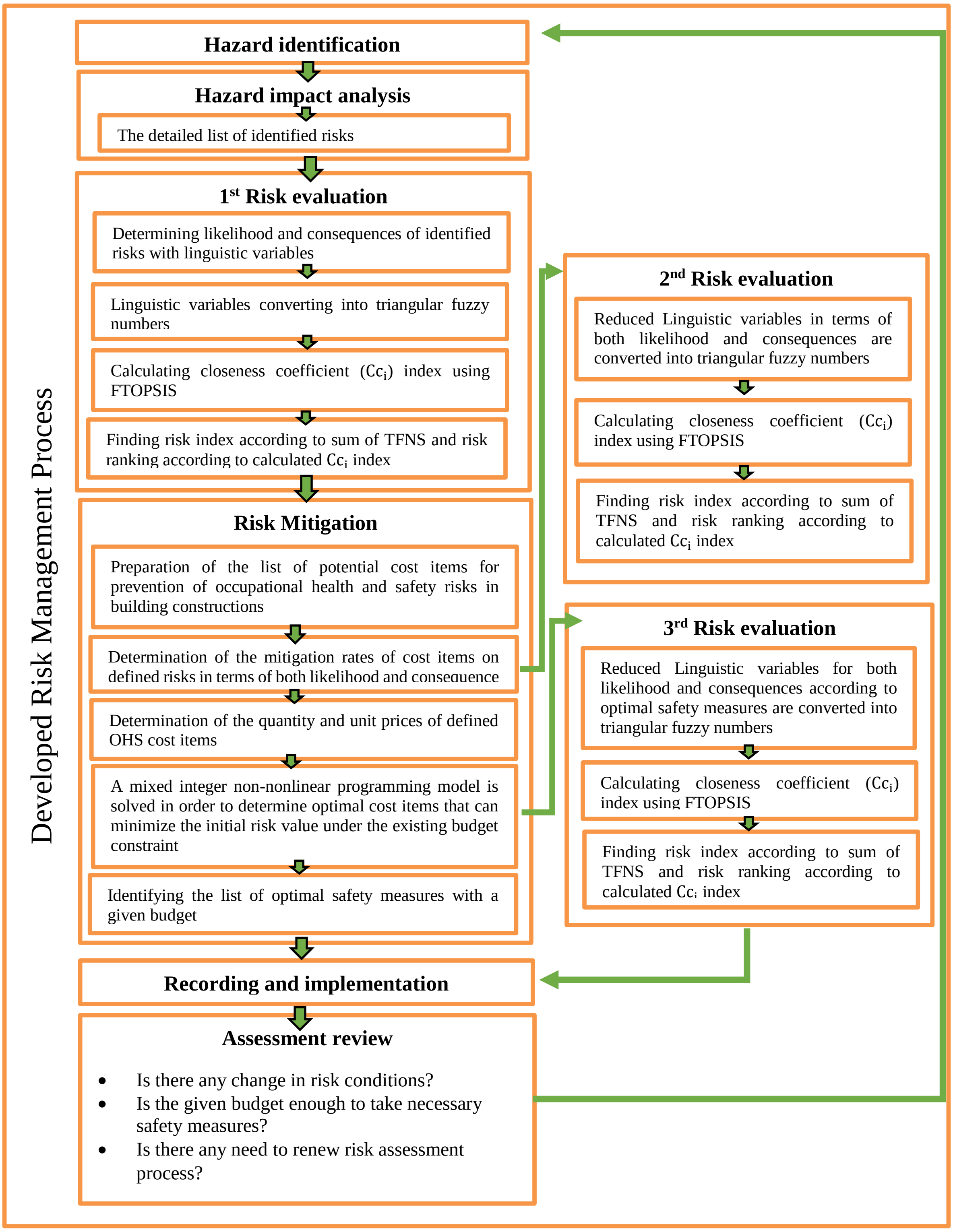


Figure 6.1. Flow Chart of the Developed Method

6.4. Steps of the Developed Method

The developed risk management method is consists of five-steps and it is based on the previously mentioned HSE risk assessment process (Neathey et al. 2006).

These five steps are;

- Identifying hazards. (**Hazard identification)**
- Determining who could be harmed and how. (**Hazard impact analysis)**
- Risk evaluation and decision making on precautions to mitigate these risks. **(Risk evaluation and mitigation)**
- Recording and implementing emerging Risk data. (**Recording and implementation)**
- Reviewing the risk assessment according to the change of the current situation and update if necessary. (**Assessment review)**

6.4.1. Hazard Identification and Hazard Impact Analysis

For the first step of the proposed risk management method, hazards were identified for building construction based on literature review and experience of safety experts. After that, hazard impact analysis was done based according to identified hazards to determine how the identified risks will occur and who may be affected. This analysis was again based on the literature review and the experience of safety experts. Then, by considering both the hazard identification and the hazard impact analysis, a detailed list of OHS risks shown in Table 6.1 was prepared. The list consists of thirty OHS risks under ten main OHS risk group. Also, there is a heading as other risk groups that contain noise, vibration, hand injuries during the use of hand tools, injured with the sharp-edged object etc. These safety risks are not referred very often in the literature by researchers. Therefore, they were grouped as other risk groups under this main heading in consultation with safety experts. The prepared list of OHS risks for building construction is shown below;

Table 6.1. List of OHS Risks in Building Construction

Human fall
Falling from the edge of the platforms and floors
Falling from scaffolding
Falling into floor openings in the construction (elevator shaft, stairwell, atrium etc.)
Falling from the Roofs
Falling on the same level
Falling from the ladder
Falling from the stairs
Falling from the hoist
Falling into the gaps on the ground floor
Falling material
Material falling from the upper floors
Material falling from the vehicle (crane, truck, hoist, backhoe loader etc.) during loading and unloading
Dropping material on to the feet during manual handling
Tilting over from the material stock
Material falling from the slope
Material splashes
Splashes of stone pieces
Splashes of machine parts
Collapse of the excavation edges
Collapse of the foundation edges
Slope collapse during excavations on the slopes
Collapse of the structure part
Collapse of the structure during construction (formworks, reinforced concrete structure etc.)
Electrical accident
Conductive material contacts with voltage lines near structure
Electrical Leakage from a power tool
Electrical Leakage from electrical panels, extension and energy cables
Accidents in the explosive use
Construction machinery accidents
Overturning of the construction vehicles
Workers struck by a construction vehicle
Material drop on to the top of the construction vehicle
Getting stuck under the construction vehicles
Loss of limb during working with construction machines
Fire
Other risk groups (noise, vibration, hand injuries during the use of hand tools, injured with the sharp-edged object etc.)

6.4.2. Risk Evaluation Process

After the identification of hazards and impact analysis, a risk evaluation process was done for identified hazards. Proposed risk management method is based on qualitative data rather than quantitative data. So, in this part of the proposed risk management method, Fuzzy TOPSIS method was adapted and integrated into this method to cope with these qualitative data which are based on subjectivity and uncertainty of safety expert judgments.

Safety experts' judgments are based on linguistic variables and with the help of fuzzy theory, these linguistic variables were translated into numerical values in terms of likelihood and consequence of the identified risk. Risk equals to the product of likelihood and consequences of determined hazards. In FTOPSIS method, likelihood can be defined as probability of occurrence of a determined hazard and described in qualitative linguistic terms From L1 to L5 as shown in Table 6.2. On the other hand, Consequence can be defined as outcomes of occurrence of a determined hazard and described in qualitative linguistic terms From C1 to C5 as shown in Table 6.3.

Table 6.2. Qualitative Description of the Likelihoods (adapted from Mahdevari et al. 2014)

Likelihood	Linguistic expression	Definition
L1	Rare	Only in exceptional conditions can occur
L2	Unlikely	Not likely to occur under normal conditions
L3	Possible	Can appear in a moment
L4	Likely (probable)	Probably occurs in most conditions
L5	Almost certain	Expected to happen in most conditions

Table 6.3. Qualitative Description of the Consequences (adapted from Mahdevari et al. 2014)

Consequence	Linguistic expression	Definition
C1	Insignificant	Injuries not needed first aid
C2	Minor (tolerable)	First aid needed
C3	Moderate	More than first aid, medical treatment needed
C4	Likely (probable)	Hospitalization needed
C5	Almost certain	Death or permanent disability to one or more persons

In The proposed FTOPSIS method, triangular fuzzy numbers are used in order to transform qualitative linguistic terms into numerical data in order to be used in mathematical calculations. The corresponding triangular fuzzy numbers for the listed likelihood and consequences are shown in Table 6.4. These triangular fuzzy scales can be different, there is no accepted certainty about these scales in the literature, but these scales must be determined in accordance with certain rules which was mentioned in chapter 5. In this tool, rather than recreating, triangular fuzzy scales were selected based on the study of Mahdevari et al. (2014). Different fuzzy scales may give different results, and therefore uncertainty may arise about the accuracy of the results obtained. In order to prevent this, a triangular fuzzy scale which was used in the study of Mahdevari et al. (2014) was chosen.

Table 6.4. Triangular Fuzzy Scale for Rating Linguistic Terms (adapted from Mahdevari et al. 2014)

Linguistic scale		Triangular fuzzy scale
Likelihood	Consequence	TFNs (Min, Mean, Max)
L1	C1	(0, 0.1, 0.25)
L2	C2	(0.15, 0.3, 0.45)
L3	C3	(0.35, 0.5, 0.65)
L4	C4	(0.55, 0.7, 0.85)
L5	C5	(0.75, 0.9, 1)

In this part, the risk evaluation process is carried out according to the given OHS risks list. Users evaluate these thirty OHS risks according to the given linguistic expression table in terms of both likelihood and consequences. After that, with the help of FTOPSIS, first, the determined linguistic variables are converted into triangular fuzzy numbers according to Table 6.4. Later, according to the FTOPSIS method that was described previously in detail, mathematical operations are performed in the specified order. In the final step of FTOPSIS, closeness coefficient (Cc_i) of each risk item is obtained according to the distance of each risk from the FPIS (d_i^+) and FNIS (d_i^-) and the risks can be ranked according to their "Cc_i" index.

This risk evaluation process can be repeated until the desired number of participants is reached. People are as unique as the construction projects, so; their judgements, experience and the perspective on events is different from each other. By increasing the number of participants, final data can be found more accurately with the help of different safety experts.

In this method, the effects of all participants were evaluated at the same level because they determine both likelihood and consequence on the same scale according to given table. Therefore, the values entered from 1 to 5 in terms of both likelihood and consequences were averaged according to number of participants for that risk in risk evaluation process. For this reason, when the number of participants increases, the averaged values become rational number in the range between 1 and 5 in terms of both likelihood and consequence. After that, the triangular fuzzy numbers (min, mean, max) corresponding to these rational numbers are found by curve fitting for finding the equation for a line of best fit according to the data in the given Table 6.4. As a result of curve fitting min, mean and max values of triangular fuzzy numbers found respectively according to Eqs. (6.1) to (6.3), and their graph is shown respectively in Figures 6.2, 6.3, and 6.4.

For min values;

y =-0.21+0.19x (6.1)

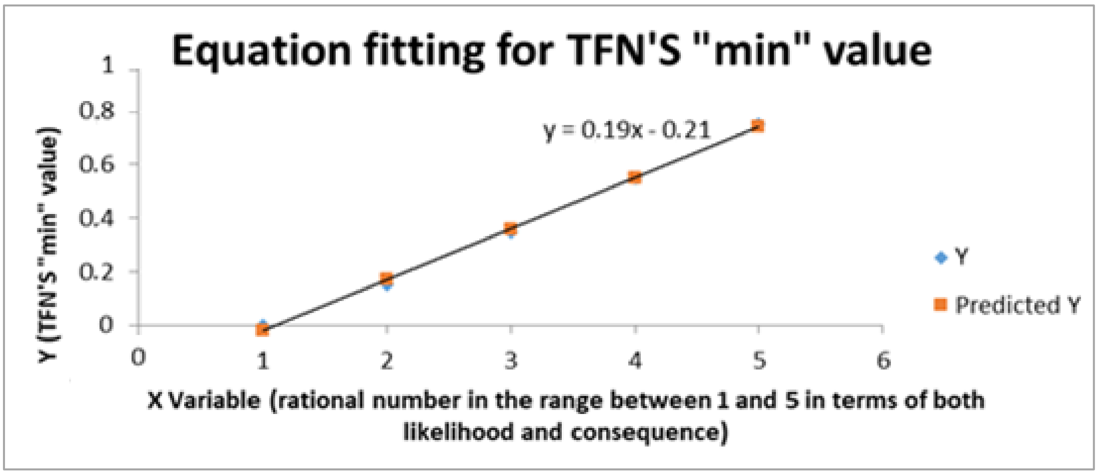


Figure 6.2. Equation Fitting for TFN'S "min" Value

For mean values;

y = -0.1+ 0.2x (6.2)

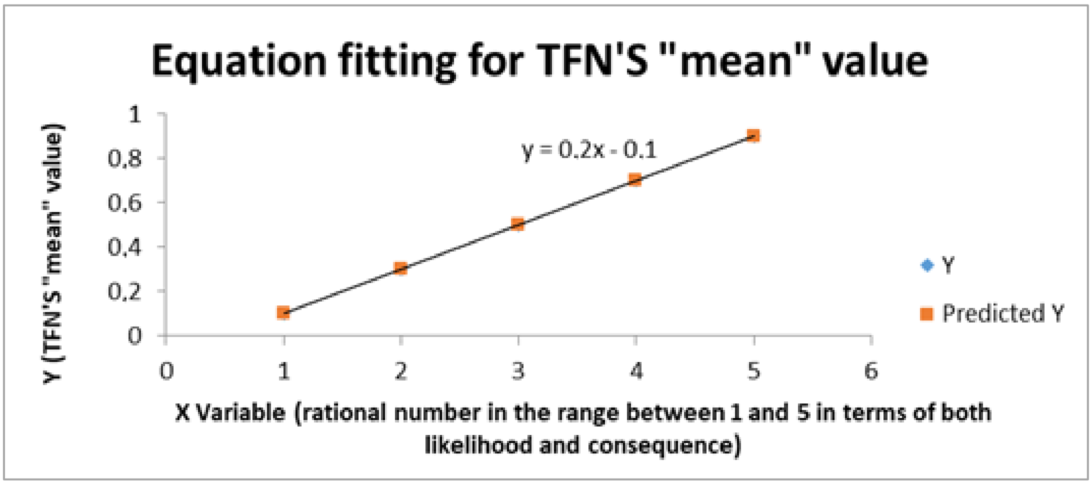


Figure 6.3. Equation Fitting for TFN'S "mean" Value

For max values;

$$y = 0.07 + 0.19x \tag{6.3}$$

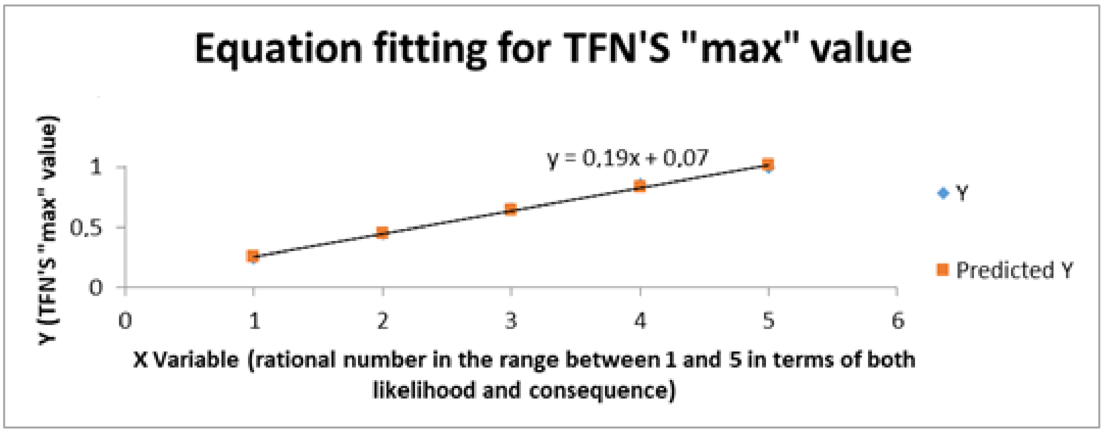


Figure 6.4. Equation Fitting for TFN'S "max" Value

Therefore, in cases where there is more than one participant, the FTOPSIS method provides a solution for rational number according to the triangular fuzzy numbers by finding the equations for "min", "mean", "max" values.

In this part, a novel theory is proposed about finding risk index by using FTOPSIS, which is not found in the literature. To find risk index, first the conditions for minimum risk and maximum risk are found by defining all likelihood and consequence values as C1, L1 and C5, L5 respectively. According to triangular fuzzy numbers which are found in FTOPSIS solution, their min, mean and max values are added, and the total value is found for both conditions. For minimum risk condition, where all values are defined as L1 and C1 for defined thirty risks, risk index was found as "2.37".On the other hand, for maximum risk condition, where all values are defined as L5 and C5 for defined thirty risks, risk index was found as "71.97". The risk index of performed risk assessment according to developed method is also found according to sum of triangular fuzzy numbers (min, mean, max) for both likelihood and consequences which was determined by users. So, for these defined thirty safety risk, the risk index can be within the range "2.37" and "71.97" according to risk evaluation process.

It was left to the user to interpret the resulting risk index whether it is in the acceptable level or not. Because it is known that safety professionals use subjective linguistic terms for assessing risks instead of definite judgments and they have different risk acceptance criteria. Also, there is no defined acceptable risk acceptance criterion in any legal legislation and regulation. So, it means that for different projects, risk acceptance levels are different according to unique nature of construction projects. The risk assessments of each project are also unique. Due to these reasons, the proposed theory for finding risk index is specific for the project and is intended only as a guide for the user in the process of determination of risk level.

At the end of this part, risks are evaluated based on proposed method by using FTOPSIS, and initial risk index and risk rankings are shown to the users as a result of FTOPSIS.

6.4.3. Risk Mitigation Process

After finding the initial risk index and the initial ranking of identified risks, risk mitigation part was included in the process, and the risk assessment process was continued for decision making on precautions to mitigate determined risks. The aim of this part is to determine the effect of the OHS cost items on the predetermined risks in terms of both likelihood and consequence and to perform a second risk evaluation process according to these effects.

In this part, the list of potential cost items for prevention of occupational health and safety risks in building constructions that shown in Table 6.5 was determined according to both literature review, market research, experiences of safety experts and OHS law no.6331. The prepared list was given to the users, and the effects of the cost items on the determined risks in terms of both likelihood and consequences are defined by the users according to this list.

The proposed list consists of five main headings listed below as;

- Personnel expenses for occupational health and safety
- Expenses for occupational health and safety training
- Pre-job and periodic health and safety training
- Expenses for the collective protective measures
- Personal protective equipment

This list also includes minimum OHS measures for building construction which are stated by the OHS law no.6331. This law becomes guidance for contractors regarding which measures have to be taken in what way and the rules to be followed while taking the stated measures. However, it does not contain conclusive judgments about the materials that should be used to take the stated measures. For example, the law specifies how to close the edge of the floors, platforms, scaffolding, stairwells, gangways, excavation areas, floor openings (elevator shaft, stairwell, atrium etc.) and what rules must be obeyed while closing the edges. However, it does not specify which material should be used to close the edges.

Therefore, this law defines minimum OHS measures as detailed general rules for construction work items rather than strictly specified measures. However, each construction projects are different from each other and therefore existing work items may differ from project to project. Because of that reason, the minimum OHS measures that are stated in the law will also vary from project to project. For example, on a construction site where explosive materials are not required, it is not necessary to take the measures specified in the law for this work item.

However, there are universal OHS measures that should be taken, such as wearing a safety helmet and steel toe safety shoes, for all construction works and projects. So, within the minimum OHS measures specified in the law, the universal OHS measures that will not vary from project to project were determined with the help of safety experts. Twenty-five of the ninety-four cost items included in the given list are evaluated and highlighted in the same table. Users have to meet these obligated universal OHS measures in order to ensure safer working environment. This way, the developed method aims to meet minimum OHS measures according to at least OHS law no.6331.

Also, different solutions have been offered to the users in order to prevent a certain OHS risk, and they have been allowed to choose the one that suits them more. The list consists of ninety-four potential cost items to reduce occupational health and safety risks in building constructions under five main headings. The list of potential cost items for prevention of occupational health and safety risks in building constructions are shown below;

Table 6.5. The List of Potential Cost Items for Prevention of OHS Risks in Building Constructions

PERSONNEL EXPENSES FOR OCCUPATIONAL HEALTH AND SAFETY	
1	OHS Coordinator (class A)
2	OHS assistant
3	Occupational physician (full or part-time))
4	Medical assistant (necessity for the construction site where more than 50 employees works)
5	OHS worker
6	OHS consultancy services
EXPENSES FOR OCCUPATIONAL HEALTH AND SAFETY TRAINING	
1	Fire training (one trained worker is necessary for 30 workers)
2	Training for workers who will works at height
3	First Aid Training and Certification (one trained and certificated worker is necessary for 30 workers)
4	Emergency Training (for management system representatives and workers in practice)
5	System Training (at the beginning of work and periodically)(at least sixteen hours for very dangerous workplaces)
6	Rigger training
7	Training to workers who works with chemical materials
8	Training for occupational health and safety managers
9	Trainings for Management Systems Representatives

Table 6.5. The List of Potential Cost Items for Prevention of OHS Risks in Building Constructions (continued)

	PRE-JOB AND PERIODIC HEALTH EXPENCES
1	Health screening (audiogram, pleurography, blood and liver tests, kidney function tests)
2	Medical equipment for Health Care (sphygmomanometer, stethoscope, ophthalmoscope, otoscope, ear curette, abeslang, body degree, surgical suture set, dressing materials, injection material, weighing table, examination table, folding screen, medicine cabinet, medical equipment cabinet, stretcher, oxygen tube refrigerator)
3	Office supplies
3.1	Health Unit Office Supplies (computer, desk and chair, visitor chair, stationery equipment, file cabinet etc.)
3.2	Occupational health and safety office supplies (computer, projector, desk and chair, whiteboard, stationery equipment, file cabinet etc.)

	EXPENSES FOR THE COLLECTIVE PROTECTIVE MEASURES
1	Warning signs (fire, traffic rules, environment, OHS, emergency, Construction site entrance and exit, electricity etc.)
2	Warning and announcement boards
3	Luminaire for emergency and exit (are able to work in power cuts)
4	Luminaire for general purpose (indoor and outdoor spaces, pedestrian and vehicle roads, dormitories and office areas)
5	Correcting deficiencies of cranes, people and freight elevators and all types of construction vehicles (reversible siren, truck covers, first aid kit, fire extinguisher, legal permissions, periodic checks and maintenance etc.)
6	Lifting slings and chains, safety ropes and safety catches
7	Ladders (with non-slip steps and support points (ladders longer than 4 m have to be made of steel pipes and profiles.))
8	Mobile scaffolding (have to have braking system and guard rails and corrosion-resistant.)
9	Materials needed to close floor openings (elevator shaft, stairwell, atrium etc.)
9.1	Closing floor openings with safety nets on certain floors considering minimum safety standards (TS 1263-1 and TS 1263-2) (safety nets, connection and anchorage elements are included)
9.2	Closing floor openings with safety net on certain floors considering medium safety standards (TS 1263-1 and TS 1263-2) (safety nets, connection and anchorage elements are included)
9.3	Closing every floor openings on floors with safety net considering maximum safety standards (TS 1263-1 and TS 1263-2) (safety nets, connection and anchorage elements are included)
10	Materials needed to close the edge of the floors, platforms, scaffolding, stairwells, gangways, excavation areas, floor openings (elevator shaft, stairwell, atrium, etc.) with guard rails and safety fence. (at least one of five)
10.1	Railing system with timber
10.1.1	Horizontal (timber) and vertical (timber or steel) elements including Toe board
10.1.2	Connection and anchoring elements

Table 6.5. The List of Potential Cost Items for Prevention of OHS Risks in Building Constructions (continued)

10.2	Railing system with rebar
10.2.1	Horizontal (rebar) and vertical (rebar) elements
10.2.2	Toe board (timber)
10.2.3	Plastic safety fence (need to be tear-proof and have suitable color)
10.2.4	Connection and anchoring elements
10.3	Railing system with safety barrier ready for use
10.3.1	safety barrier ready for use (have to comply with TS EN 13374 standards)
10.3.2	Connection and anchoring elements
10.4	Railing system with steel rope
10.4.1	Horizontal (steel rope) and vertical (steel) elements
10.4.2	Toe board (timber)
10.4.3	Plastic safety fence (need to be tear-proof and have suitable color)
10.4.4	Connection and anchoring elements
10.5	Complete closure of open spaces with safety nets
10.5.1	Safety nets (have to comply with TS EN 1263-1 standards)
10.5.2	Toe board (timber)
10.5.3	Connection and anchoring elements
11	Lifelines
11.1	Horizontal lifelines
11.2	Vertical lifelines
11.3	Mobile lifelines
12	Safety net fans (have to comply with TS EN 1263 standards)
13	Hydraulic Curtain System which can be climb for Wind and safety protection on the facade
14	Facade scaffolding with safety netting
15	Soft landing systems (airbags, soft filled energy-absorbing bags etc.)
16	Building entrance and exit passages (have to be Covered and protected against falling material)
17	Debris chute
18	Temporary waste storage area (paper, plastic, glass, metal, wood, non-reversible etc.)
19	Safety barrier around the construction site area (min. 2m high, with inside out buttress, closed to entrance and sight)
20	Emergency exit door
21	Fire extinguishing equipment (fire extinguisher, fire blanket etc.)
22	Suitable storage areas for hazardous and non-hazardous materials
23	Transport vehicles suitable for hazardous materials
24	Mobile electrical panels and equipment (with residual current relay)

Table 6.5. The List of Potential Cost Items for Prevention of OHS Risks in Building Constructions (continued)

25	Low-voltage transformer
26	Electrical extension cables with multiple plugs (overcurrent protection and grounded)
27	Protection of electrical cables by shielding
28	Folding screens to separate welded areas while welding
29	Rechargeable Flashlight
30	OHS warning tape
31	Traffic cones and delineators
32	Flashing warning lamp
33	Traffic Safety Mirrors
34	Speed limiters
35	Filler material for the construction of pedestrian and vehicle transportation roads (stabilized material, crushed stone, plentmix etc.)
36	Automatic security barrier at construction site entrance and exit
37	Water purifiers
38	Mobile toilets
39	Wireless communication equipment
40	Plastic safety fence (tear-proof and in suitable color)
41	Banners on occupational health and safety
42	Printing the state of distress notifications and fault report forms
43	Mobilization of dormitories (accommodation and recreational areas, dressing areas (lockers, sitting areas etc.), showers, toilets and washbasins, refectory and their equipment etc.(will be sufficient according to the number of employees))
44	Occupational health and safety handbooks
45	Fully equipped first aid kit
46	Construction project signboard

PERSONAL PROTECTIVE EQUIPMENT EXPENSES	
1	Full body harness
2	Safety helmet
3	High Visibility Safety Vest
4	Transparent face shield
5	welding masks
6	Safety goggles for Dust and chemical protection
7	Safety grinding goggles
8	Welding Oxy-Acetylene Goggle
9	Mounting Gloves
10	Mechanical and chemical resistant gloves
11	Welding gloves
12	Electrician Gloves

Table 6.5. The List of Potential Cost Items for Prevention of OHS Risks in Building Constructions (continued)

13	Ear Plug and Earmuff
14	Gas and dust masks
15	Welding apron, sleeves and gaiters
16	Steel-toe safety shoes
17	Steel-toe safety boots
18	Safety overalls
19	Reflective safety jacket or coat to have protection from cold weather
20	Raincoat
21	Lanyard and carabiners
22	Retractable fall arresters

In this part of the developed risk management method, potential cost items for prevention of occupational health and safety risks in building constructions are given to the users as a list and the mitigation effect of ninety-four cost item on defined thirty risks are determined by the users according to this list in terms of both likelihood and consequence. The mitigation effects of cost items on the identified risk are based on the risk reduction ratios. The users are allowed to determine the reduction impact of these cost items on predefined risks between 0% and 80%. 0% means that cost item has no effect on reducing predefined risk. On the other hand, 80% means that cost item has reduced risk by eighty percent. The reduction rate was limited to eighty percent because the likelihood and consequence of determined hazards were scaled linguistically from 1 to 5. So, to reduce risk scale from 5 to 1, maximum reduction rate can become eighty percent.

One cost item may affect more than one risk in different rates, and it may vary from project to project depending on the unique nature of construction projects. Risk is determined by multiplying of likelihood and consequences. In addition, a cost item may mitigate the identified risk only in terms of consequence and may not have an impact on the likelihood. For example, wearing safety helmet has no effect on the probability of material falling from the upper floors; however, it causes the worker to be injured more lightly when material falls from above. Therefore, wearing safety helmet mitigates the consequence of identified risk but not effects the likelihood. That is why there are sixty data to be filled in for each cost item because there are thirty predetermined risk and users were asked to evaluate cost items for each risk in terms of likelihood and consequences. If cost item affects defined risk, users should fill all the boxes according to their experience, foresight and preliminary studies.

The list of potential cost items for the prevention of occupational health and safety risks in building constructions are prepared to serve as a guidance for the user. Therefore, users are free to choose the desired cost items from this list, according to their projects, with the exception of universal OHS measures marked in the list and required by law. It means that users do not have to determine the mitigation rate of all the cost items presented in the list to the risks. However, considering that this list is determined according to both literature review, market research, experiences of safety experts and OHS law no.6331, to incorporate most of these cost items in this list into the risk assessment process will contribute to a safer working environment.

There are ninety-four cost items to mitigate identified thirty risks, therefore, if user determines all mitigation rates as 2%, total reduction rate for one risk become 188%. This means that even if the initial risk is assessed at the top level as 5, this is impossible to reduce risk by 188%. A new theory is proposed based on normalization method to solve this problem, considering that the users will determine values greater than 2% and consequently the total risk reduction rates will be much higher. Therefore, after determining the mitigation rates of the selected cost items to the risks by the users, the total reduction rates for each risk item are summed up separately in terms of both likelihood and consequences. Then, the risk with the highest total reduction rate is selected and proportioned according to the maximum reduction rate percentage that was predetermined as 80%. The resulting ratio is multiplied by all risk reduction rates set by the user and new mitigation values are determined in order to integrate into risk assessment process. By doing this, the mitigation rates determined by the user is scaled to the level that can be integrated into the proposed method without changing the scale that the user determined.

Unlike the initial risk evaluation process, this part can only be filled by one user in order not to evaluate risk reduction rates based on different value judgments of different users. In the initial risk evaluation process, risks were evaluated by different users based on the table given on a specific scale. Therefore, the increase in the number of users does not constitute any inconsistency because the risk assessment scale is the same, even if the users are different. On the other hand, there is no defined scale for mitigation rates of cost item for identified risks. So, users are asked to make an assessment in accordance with the given range based on their subjective judgment and experience. People are as unique as construction projects, so; their judgements, experience and the perspective on events is different from each other. So, in an assessment where there is no specific scale, decisions made by different users will result in inconsistency. This is why this section can only be filled by one user.

After the mitigation rates of cost items on defined risks in terms of both likelihood and consequence were determined by the user, the second risk evaluation process is performed according to reduced risk levels by using developed method. At the end of this part, as a result of this risk evaluation process, the user will be able to see the minimum risk value and the new risk ranking in the scenario where all these measures are taken.

After the second risk evaluation process was over, the user moves to the next part of the proposed method. The aim of this part is to determine quantity and unit prices of defined OHS cost items to find total cost of safety measures for construction project. The quantities of these cost items can be found by project drawings, experience of safety experts, number of employees and project information. On the other hand, unit prices can be found by market research method. This page can only be filled by one user because quantities and unit prices of OHS cost item cannot be changed from person to person. Therefore, to find quantities and unit prices of defined OHS cost items more accurately, preliminary studies can be carried out by groups of experts.

6.4.3.1. A Mixed Integer Nonlinear Programming (MINLP) Model

After determining total costs of safety cost items, mixed-integer nonlinear programming (MINLP) model was developed and solved by Generalized Reduced Gradient (GRG) nonlinear optimization solver in Excel Solver, in order to determine optimal cost items that can minimize the initial risk value under the existing budget constraint. Risk equals to product of triangular fuzzy number derived from likelihood and consequences of determined hazards. Therefore, the model developed is based on mixed-integer nonlinear programming (MINLP). The objective function is minimization of sum of all triangular fuzzy number (min, mean, max) values of thirty defined risks in terms of both likelihood and consequence. As previously mentioned, the risk index is found by sum of all triangular fuzzy number (min, mean, max) values of thirty defined risks after risk evaluation process. What follows is the details of the proposed model.

Definitions of Model Inputs

Sets

I: Occupational health and safety risks in building construction, $i = 1,...,30$.

J: Potential cost items for prevention of occupational health and safety risks in building constructions, $j = 1,…,94$.

Parameters

CT_i : The value of Consequence (C) of risk i from initial risk evaluation process.

LT_i : The value of Likelihood (L) of risk i from initial risk evaluation process.

RX_jC_i : The normalized reduction rate of cost item j on OHS risk i in terms of Consequence (C).

RX_jL_i : The normalized reduction rate of cost item j on OHS risk i in terms of Likelihood (L).

Budget: Given budget by users.

B_j : The total cost of cost item j.

Variables

Z : Sum of all triangular fuzzy number (min, mean, max) values of thirty defined risks in terms of both likelihood and consequence.

X_j : $\begin{cases} 1 & \text{if cost item i is selected;} \\ 0 & \text{else.} \end{cases}$

C_i : The value of Consequence (C) of risk i according to selected cost items.

L_i : The value of Likelihood (L) of risk i according to selected cost items.

($Cmin_{i,}$ $Cmean_{i,}$ $Cmax_i$) : The triangular fuzzy numbers of Consequence (C) of risk i according to selected cost items.

($Lmin_{i,}$ $Lmean_{i,}$ $Lmax_i$) : The triangular fuzzy numbers of Likelihood (L) of risk i according to selected cost items.

Modeling

Minimize

$$Z = \sum_{i=1}^{30} ((Cmin_i \times Lmin_i) + (Cmean_i \times Lmean_i) + (Cmax_i \times Lmax_i)) \quad (6.1)$$

Subject to;

$$Cmin_i = -0.21 + 0.19 \text{ x } C_i \qquad \forall_i \in I \qquad (6.2)$$

$$Lmin_i = -0.21 + 0.19 \text{ x } L_i \qquad \forall_i \in I \qquad (6.3)$$

$$Cmean_i = -0.1 + 0.2 \text{ x } C_i \qquad \forall_i \in I \qquad (6.4)$$

$$Lmean_i = -0.1 + 0.2 \text{ x } L_i \qquad \forall_i \in I \qquad (6.5)$$

$$Cmax_i = -0.07 + 0.19 \text{ x } C_i \qquad \forall_i \in I \qquad (6.6)$$

$$Lmax_i = -0.07 + 0.19 \text{ x } L_i \qquad \forall_i \in I \qquad (6.7)$$

$C_i \geq 1 \ \forall_i \in \mathrm{I}$ (6.8)

$L_i \geq 1 \ \forall_i \in \mathrm{I}$ (6.9)

$$C_i \geq CT_i \times (1 - \sum_{j=1}^{94} (X_j \times RX_jC_i)) \quad \forall \mathrm{i} \in \mathrm{I} \tag{6.10}$$

$$L_i \geq LT_i \times (1 - \sum_{j=1}^{94} (X_j \times RX_jL_i)) \quad \forall \mathrm{i} \in \mathrm{I} \tag{6.11}$$

$$\sum_{j=1}^{94} (X_j \times B_j) \leq Budget \tag{6.12}$$

Equation 6.1 aims to minimize the Sum of all triangular fuzzy number (min, mean, max) values of thirty defined risks in terms of both likelihood and consequence. Equation 6.2 to 6.7 finds the TFNs min, mean and max values of the consequences and the likelihoods of the risk i. Equation 6.8 prevents the new consequence value of the risk i from being below 1. Equation 6.9 prevents the new likelihood value of the risk i from being below 1. Equation 6.10 makes sure that the final C values of risk i cannot be lower than the allowed reduction from each chosen action j. Equation 6.11 makes sure that the final L values of risk i cannot be lower than the allowed reduction from each chosen action j. With the equation 6.12, the sum of all chosen costs of safety measures is limited with the given budget.

The mixed-integer nonlinear programming model has been implemented into an MS Excel file. Instance input data is entered in MS Excel. The problem data is prepared according to the model by the Excel file, and then, computational processes are performed by MS Excel Solver.

After finding optimal safety measures with a given budget, a third and final risk evaluation process is performed according to optimal safety measures and their determined mitigation rates for defined risks in terms of both likelihood and consequence. According to the results of final risk evaluation process, users can see final risk index and risk rankings according to the given budget. Also, users can see the list of optimum safety measures that were determined according to given budget by developed mixed-integer nonlinear programming (MINLP) model.

With this final stage, the developed method has achieved its aim for finding optimal safety measures with a given budget for building construction and provides a list of optimum cost items and shows current risk index and risk rankings based on a given budget. By using this method, users are also able to set and try different budget values easily to reduce the current risk index for a safer work environment.

6.4.4. Recording and Implementation

Risk values achieved during the proposed risk assessment process should be recorded for both in terms of facilitating the work of the occupational safety professionals and legal regulations and legislations.

6.4.5. Assessment Review

The proposed method allows the risk assessments to be reviewed and renewed if;

- There are any changes in risk conditions.
- The given budget is not enough to take the necessary safety measures.
- There is any need to renew risk assessment process.

Risk assessment should also be renewed within a certain period of time according to the legal regulations and legislations. In accordance with OHS law no.6331, performed risk assessment is valid for two years.

CHAPTER 7

EXCEL TOOL FOR IMPLEMENTING DEVELOPED RISK MANAGEMENT METHOD

To implement the developed risk management method and to reach the users, MS Excel Tool has been created using VBA (Visual Basic for Applications). The main page of the risk assessment tool has a simple user interface shown in Figure 7.1. User can manage this tool from this page. The developed method is divided into two parts as initial risk evaluation process and finding optimal safety measures with given budget in accordance with this initial risk evaluation process. Users cannot move to the second part without finishing the first part. This is prevented because the formation of the second part depends on the initial risk evaluation process.

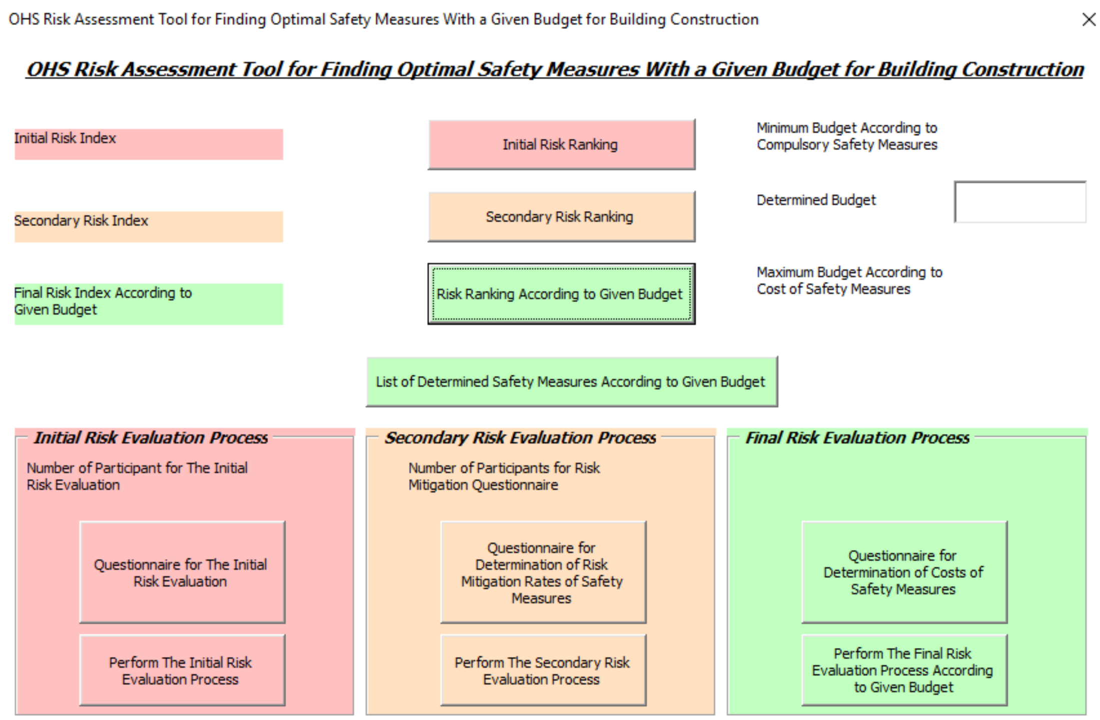
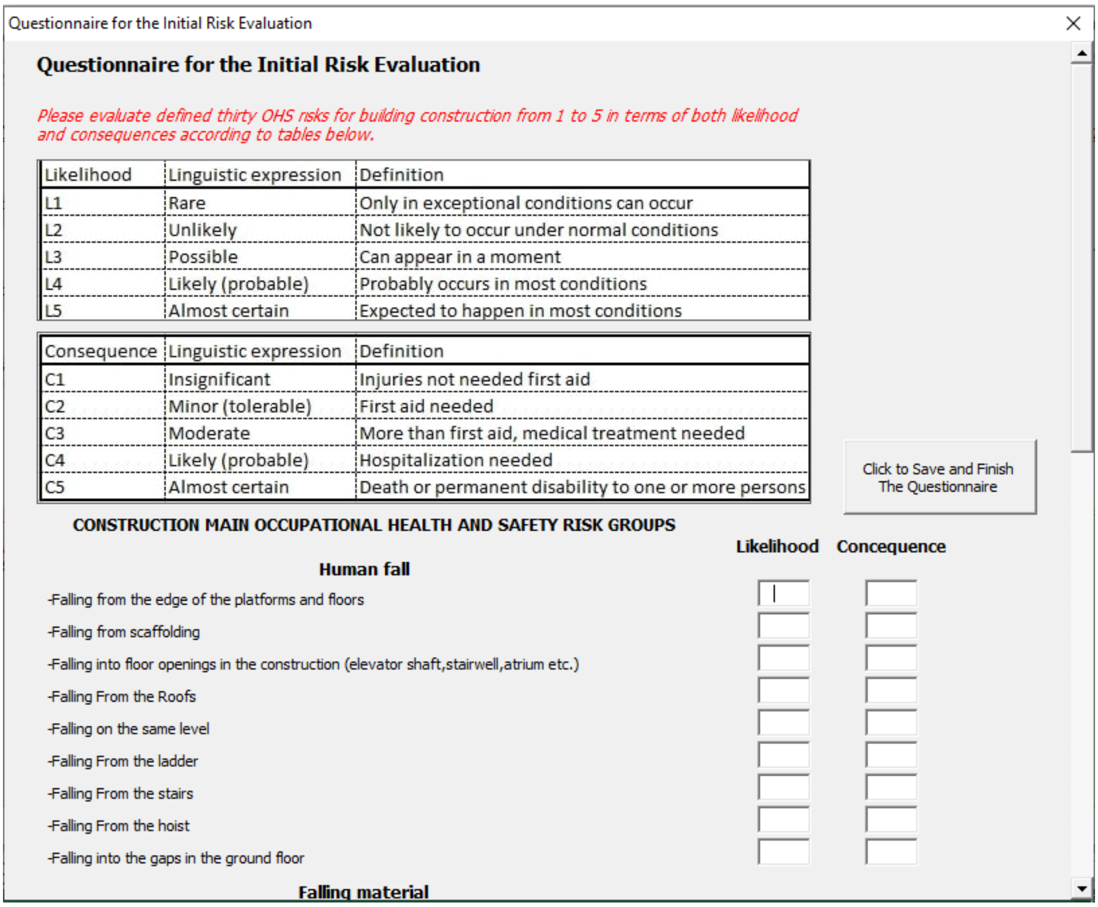


Figure 7.1. User Interface of the Developed Excel Tool

The user can start the first part of this tool by clicking "Questionnaire for The Initial Risk Evaluation" button. The aim of this part is to evaluate determined risks according to expert judgments, determine initial risk index and rank these risks by using the developed risk management method. After clicking the button, the list of main OHS risks in building construction shown in Figure 7.2 will appear on the new page.


Questionnaire for the Initial Risk Evaluation

Questionnaire for the Initial Risk Evaluation

Please evaluate defined thirty OHS risks for building construction from 1 to 5 in terms of both likelihood and consequences according to tables below.

Likelihood	Linguistic expression	Definition
L1	Rare	Only in exceptional conditions can occur
L2	Unlikely	Not likely to occur under normal conditions
L3	Possible	Can appear in a moment
L4	Likely (probable)	Probably occurs in most conditions
L5	Almost certain	Expected to happen in most conditions

Consequence	Linguistic expression	Definition
C1	Insignificant	Injuries not needed first aid
C2	Minor (tolerable)	First aid needed
C3	Moderate	More than first aid, medical treatment needed
C4	Likely (probable)	Hospitalization needed
C5	Almost certain	Death or permanent disability to one or more persons

Click to Save and Finish The Questionnaire

CONSTRUCTION MAIN OCCUPATIONAL HEALTH AND SAFETY RISK GROUPS

	Likelihood	Concequence
Human fall		
-Falling from the edge of the platforms and floors		
-Falling from scaffolding		
-Falling into floor openings in the construction (elevator shaft,stairwell,atrium etc.)		
-Falling From the Roofs		
-Falling on the same level		
-Falling From the ladder		
-Falling From the stairs		
-Falling From the hoist		
-Falling into the gaps in the ground floor		
Falling material		

Figure 7.2. Form for the Initial Risk Evaluation

On this page, there are two boxes next to each other in front of the construction safety risks for likelihood and consequences. Likelihood can be defined as probability of an occurrence of determined hazard and described in qualitative linguistic terms from L1 to L5 as shown in Table 6.2. On the other hand, Consequence can be defined as outcomes of an occurrence of determined hazard and described in qualitative linguistic terms from C1 to C5 as shown in Table 6.3. Risk equals to product of likelihood and consequences of determined hazards. What is expected from the users for this page is to define risks in terms of both likelihood and consequences according to the given tables. When all risk items are identified in terms of both likelihood and consequence, users click "Click to Save and Finish the Questionnaire" button to add those data to the risk evaluation process. This process is repeated until the desired number of participants is achieved, and on the main page, the total numbers of participants have shown.

When the desired number of participants is reached, this process is terminated. After that users need to be clicked the "Perform the Initial Risk Evaluation Process" button which is located on the main page and shown in Figure 7.3 to perform safety risk evaluation process by using FTOPSIS with accordance to the developed method. The tool performs the risk evaluation process in the background according to the mathematical operations based on FTOPSIS method, which was described in detail before. Triangular fuzzy numbers are used to transform qualitative linguistic terms into numerical data in order to be used in mathematical calculations.

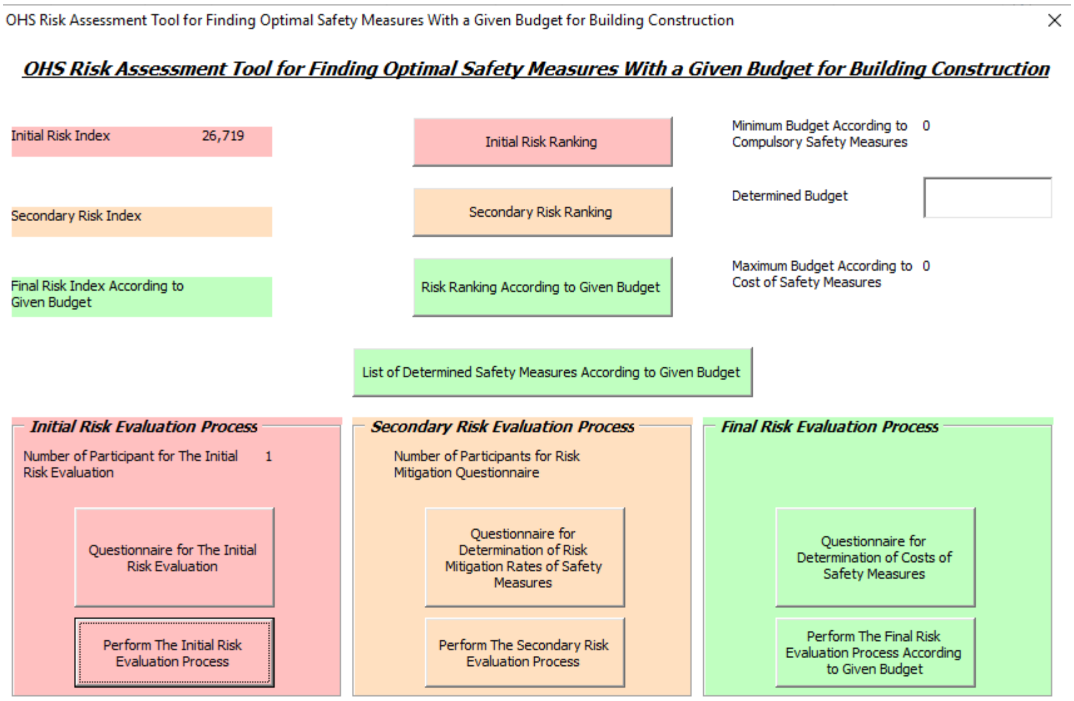


Figure 7.3. Location of the "Perform the Initial Risk Evaluation Process" Button

After the risk evaluation process is over, developed tool reveals two results to guide users. The first result is the initial risk index according to initial risk evaluation process as shown in Figure 7.4.

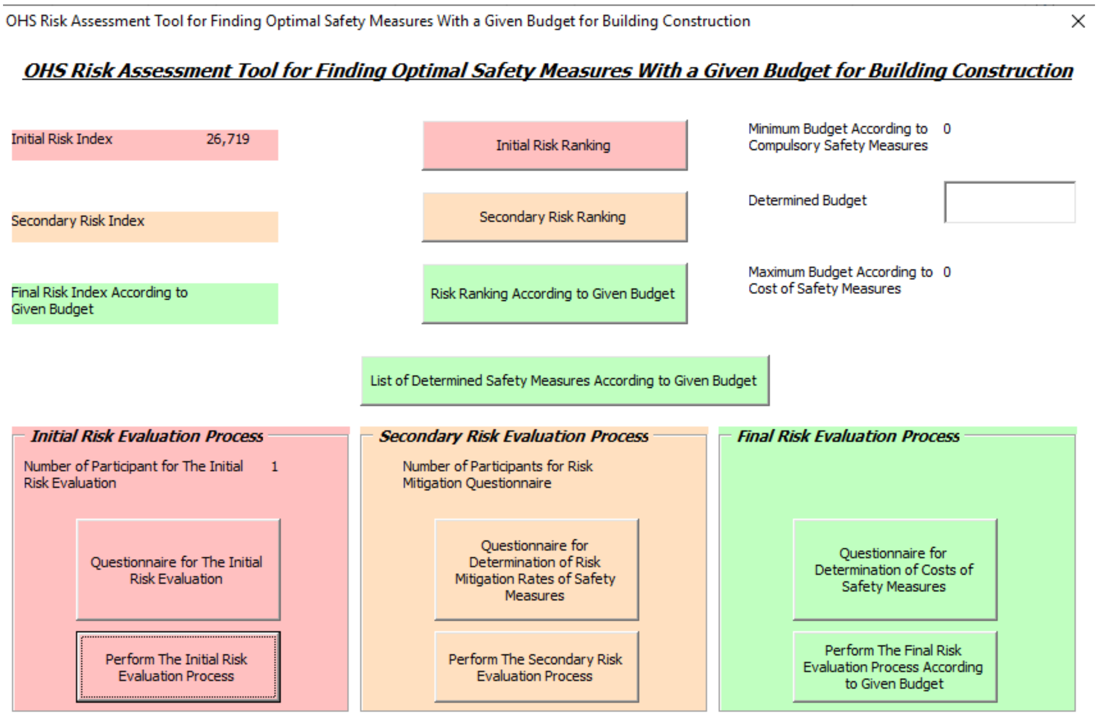
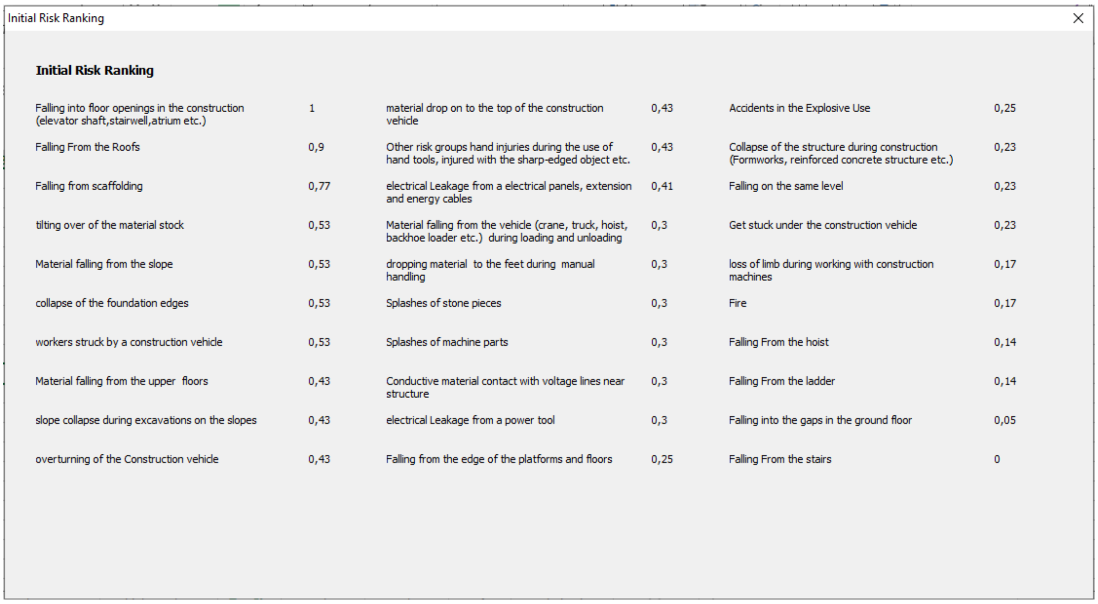


Figure 7.4. User Interface after the Initial Risk Evaluation Process Performed

The second result is the initial risk rankings according to initial risk evaluation process. Risks are ranked using their closeness coefficient (Cc_i) which is obtained as a result of FTOPSIS and users can see this ranking which is shown in Figure 7.5 by clicking "Initial Risk Ranking" button on the main page. This can also be a guide for users to determine importance of defined risks and the measures to be taken according to those risks.



Initial Risk Ranking

Initial Risk Ranking

Falling into floor openings in the construction (elevator shaft,stairwell,atrium etc.)	1	material drop on to the top of the construction vehicle	0,43	Accidents in the Explosive Use	0,25
Falling From the Roofs	0,9	Other risk groups hand injuries during the use of hand tools, injured with the sharp-edged object etc.	0,43	Collapse of the structure during construction (Formworks, reinforced concrete structure etc.)	0,23
Falling from scaffolding	0,77	electrical Leakage from a electrical panels, extension and energy cables	0,41	Falling on the same level	0,23
tilting over of the material stock	0,53	Material falling from the vehicle (crane, truck, hoist, backhoe loader etc.) during loading and unloading	0,3	Get stuck under the construction vehicle	0,23
Material falling from the slope	0,53	dropping material to the feet during manual handling	0,3	loss of limb during working with construction machines	0,17
collapse of the foundation edges	0,53	Splashes of stone pieces	0,3	Fire	0,17
workers struck by a construction vehicle	0,53	Splashes of machine parts	0,3	Falling From the hoist	0,14
Material falling from the upper floors	0,43	Conductive material contact with voltage lines near structure	0,3	Falling From the ladder	0,14
slope collapse during excavations on the slopes	0,43	electrical Leakage from a power tool	0,3	Falling into the gaps in the ground floor	0,05
overturning of the Construction vehicle	0,43	Falling from the edge of the platforms and floors	0,25	Falling From the stairs	0

Figure 7.5. Initial Risk Ranking

After the initial risk evaluation process is over, users move to the second part of the developed tool by clicking "Questionnaire for Determination of Risk Mitigation Rates of Safety Measures" button which is located on the main page. The aim of this part is to determine the mitigation rate of the OHS cost items on the defined thirty risk in terms of both likelihood and consequence and to perform a second risk evaluation process according to determined rates. In this part potential cost items for prevention of occupational health and safety risks in building, constructions are given to the users as a list, and their effects on defined risks in terms of both likelihood and consequences are determined by the users according to this list.

After clicking "Questionnaire for Determination of Risk Mitigation Rates of Safety Measures" button, the page shown in Figure 7.6 is opened. In this page potential cost items for prevention of occupational health and safety risks in building constructions are given to the users as a list, and the mitigation effect of ninety-four cost item on defined thirty risks are determined by the users according to this list in terms of both likelihood and consequence. Next to the cost items, there are sixty boxes to describe the reduction impact of these cost items on the thirty predetermined risks in terms of both likelihood and consequences. The users are allowed to determine the reduction impact of these cost items on predefined risks between 0% and 80%. 0% means that cost item has no effect on reducing predefined risk. On the other hand, 80% means that cost item has reduced risk by eighty percent.

There are sixty boxes to fill for one cost item because there are thirty predetermined risks and risk is determined by multiplying of likelihood and consequences. If cost item affects defined risk, users need to fill the corresponding boxes according to their experience and foresight. Otherwise, the proposed tool evaluates empty boxes as 0%.

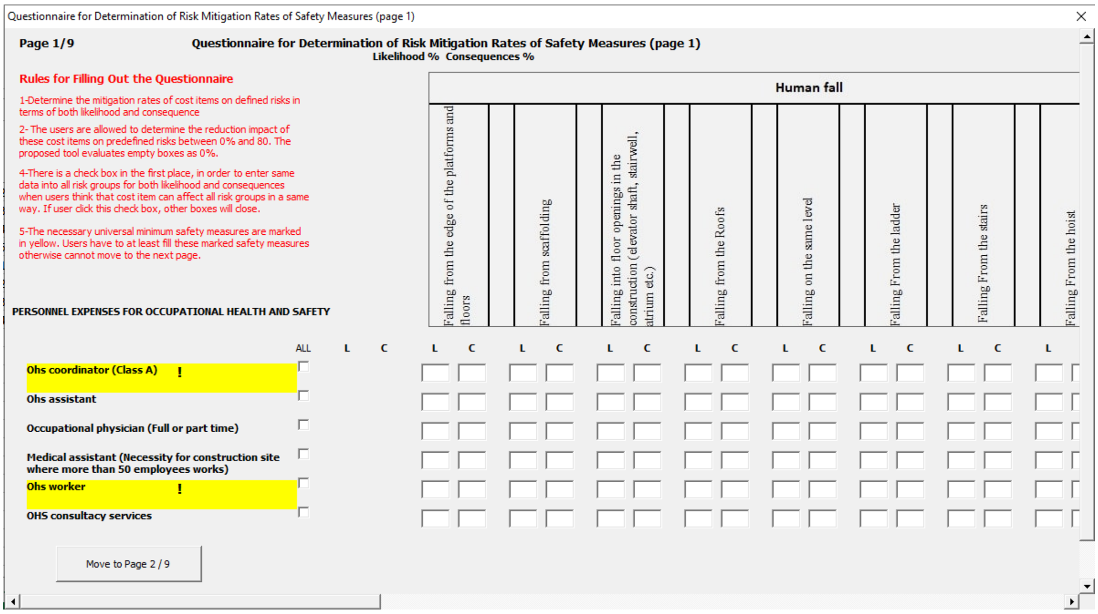


Figure 7.6. Form for Determination of Risk Mitigation Rates of Safety Measures

This form consists of nine pages and users can move between these pages. To guide users, rules for filling this form are indicated in the upper left corner on all pages. After filling the form, user click “Click to Save and Finish the Questionnaire” button that shown in Figure 7.7 to add those data to the risk evaluation process.

Within the minimum OHS measures specified in the law no.6331, the universal OHS measures that will not vary from project to project were determined with safety experts and marked on the form to be specified to users. Users have to meet these obligated universal OHS measures in order to ensure a safer working environment. In this way, the developed tool aims to meet minimum OHS measures according to at least OHS law no.6331.

Figure 7.7. Location of the "Click to Save and Finish the Questionnaire" Button at the end of the Form

After the filling process is over, the entered data are collected in the excel page in the background of the developed tool, and a normalization process is applied according to the proposed method.

This page can only be filled by one user because people are as unique as construction projects so, their judgements, experience and the perspective on events are different from each other. So, inconsistency can occur in results if different users are included in this part of the assessment.

One of the errors that can be made while entering data into the form is omitting one of the cost items. To avoid this, if no value is entered under any risk group for the cost item, the tool gives an error and allows the user to review the form again. Also, to make the filling process of this form easier for users, there are two boxes in order to enter same data into all risk groups for both likelihood and consequences when users think that cost item can affect all risk groups in the same way.

After this process is terminated, users need to click "Perform the Secondary Risk Evaluation Process" for performing the second risk evaluation process. This process reveals two results to guide users as in the first part. The first result is the new risk index that was found by developed FTOPSIS method after the reduction rate form by considering all safety measures and their effects on risks in terms of both likelihood and consequences. The second result that is shown in Figure 7.8 is the new risk rankings after the reduction rate form by considering all safety measures and their effects on risks in terms of both likelihood and consequences. Risks are ranked using their closeness coefficient (Cc_i) which is obtained as a result of FTOPSIS and users are able to see this ranking by clicking "Secondary Risk Ranking" button on the main page.

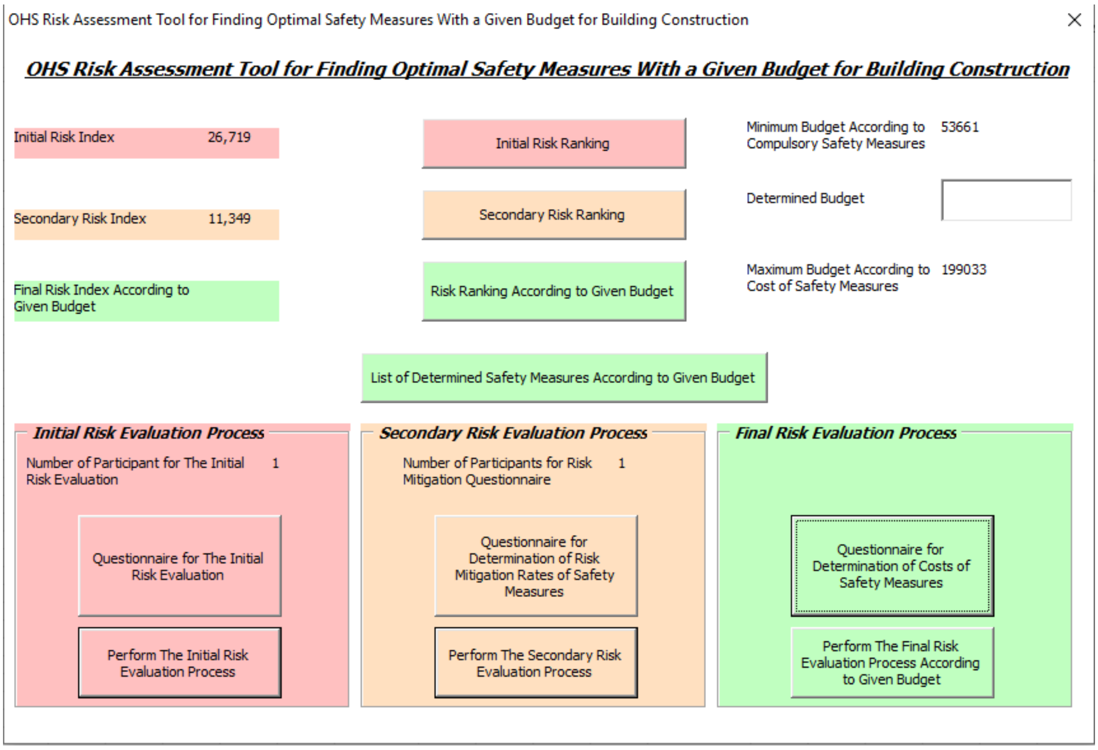


Figure 7.8. Home page after the Secondary Risk Evaluation Process Performed

After determining second risk value and rankings according to the results of the reduction rate form, users can move to another step of this tool by clicking "Questionnaire for Determination of Cost of Safety Measures" button. The aim of this part of this tool is to determine quantity and unit prices of defined OHS cost items to find total cost of safety measures for construction project. This form is shown in Figure 7.9 and consists of five pages with the same name as the list of potential cost items for prevention of occupational health and safety risks in building constructions. Each page consists of OHS cost items which are grouped under five main headings. There are two boxes for each cost item for the users to enter their quantity and unit prices. In this form, OHS cost items are automatically shown to the users if they are stated in previous part of the tool that it has risk mitigation effect by users. Otherwise, OHS cost items that specified to have no effect on risk will not be displayed in this page even if they exist in the given list. By this way, this tool has been made easier for the users by showing only evaluated OHS cost items to fill both quantities and unit prices.

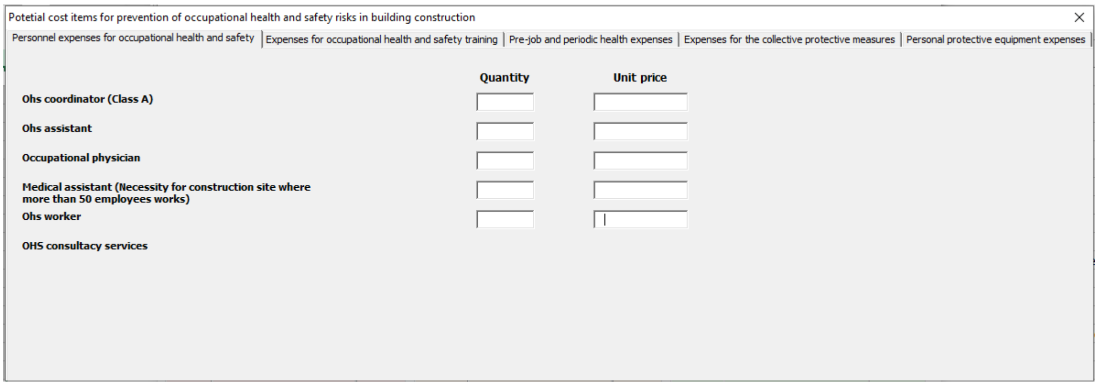


Figure 7.9. Form for Determination of Cost of Safety Measures

This page can only be filled by one user because quantities and unit prices of OHS cost item cannot be changed from person to person. Therefore, to find quantities and unit prices of defined OHS cost items more accurately, preliminary studies can be carried out by groups of users. After user filled all quantity and unit price data for OHS cost items, by clicking "Click to Save and Finish the Questionnaire "button shown in Figure 7.10, entered data can transfer to the background of the tool. If there are any empty spaces, the tool gives an error which indicates that user does not fill the necessary fields and instruct the user to fill in these boxes.

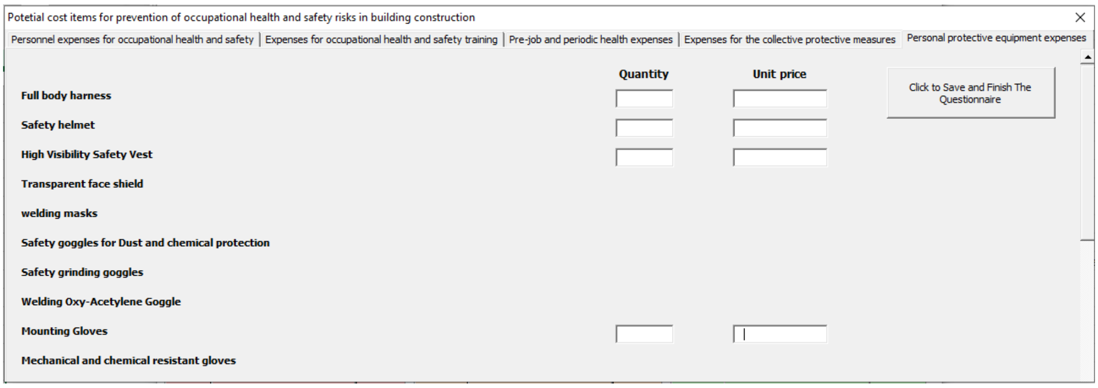


Figure 7.10. Location of the "Click to Save and Finish the Questionnaire" Button at the end of the Form

After this part, the developed tool shows the required minimum and maximum OHS budget on the main page. Minimum OHS budget is calculated based on the total costs required to meet obligated minimum universal OHS measures in accordance with the OHS law no.6331.On the other hand, maximum OHS budget is calculated based on the total costs of all OHS cost item that defined in the previous part. The main aim of the developed method is to find optimal safety measures for a given budget for building construction. To achieve this aim, there is an empty box on main page to enter the determined budget. Determined budget value needs to be between minimum and maximum budget or equals to them.

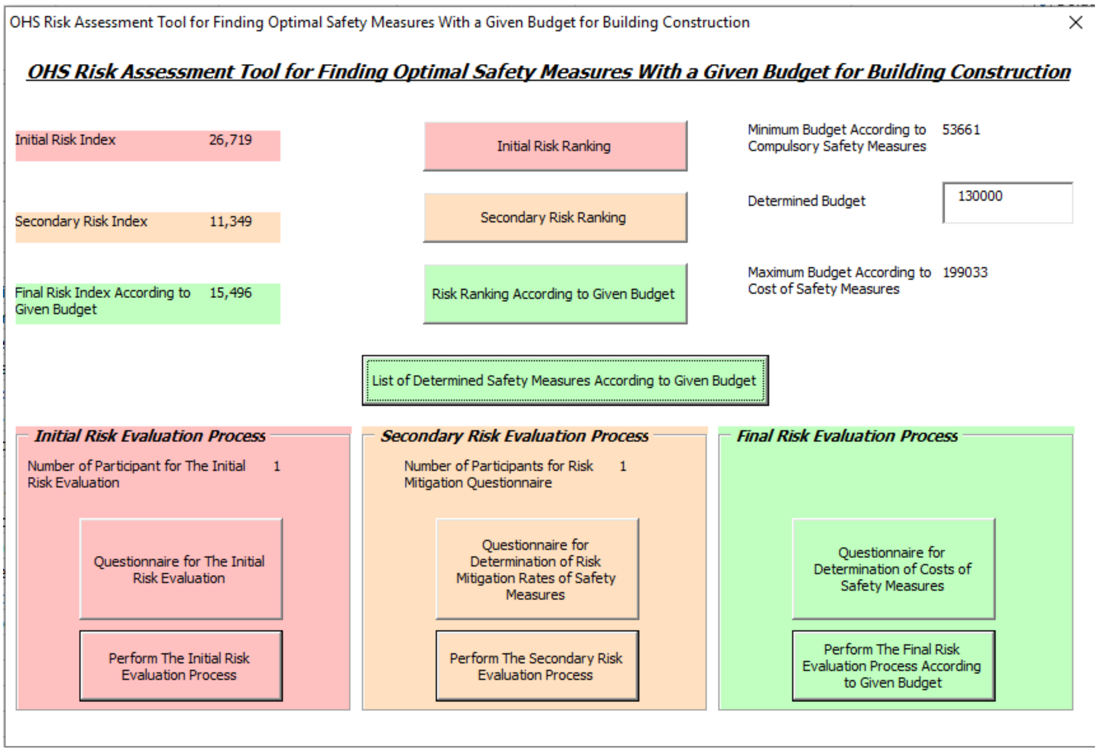


Figure 7.11. Location of the Determined Budget Box on the Main Page

After determination of OHS budget, in the main page, users fill the budget box according to determined budget value and then click "Perform the Final Risk Evaluation Process According to Given Budget" button shown in Figure 7.11. In the background of this tool the developed mixed integer nonlinear programming model is solved with Generalized Reduced Gradient (GRG) Nonlinear method by using MS Excel Solver, in order to determine optimal cost items that can minimize the initial risk value under the existing budget constraint. After performing optimization, the third and the last risk evaluation process also is performed in background, and according to the results, the tool shows to the user the final risk index and risk rankings in accordance with a given budget. Also, users can see the list of optimum safety measures shown in Figure 7.12 that was determined by developed tool according to given budget. To see this list user need to click "List of Determined Safety Measures According to Given Budget" button which is located on the main page.

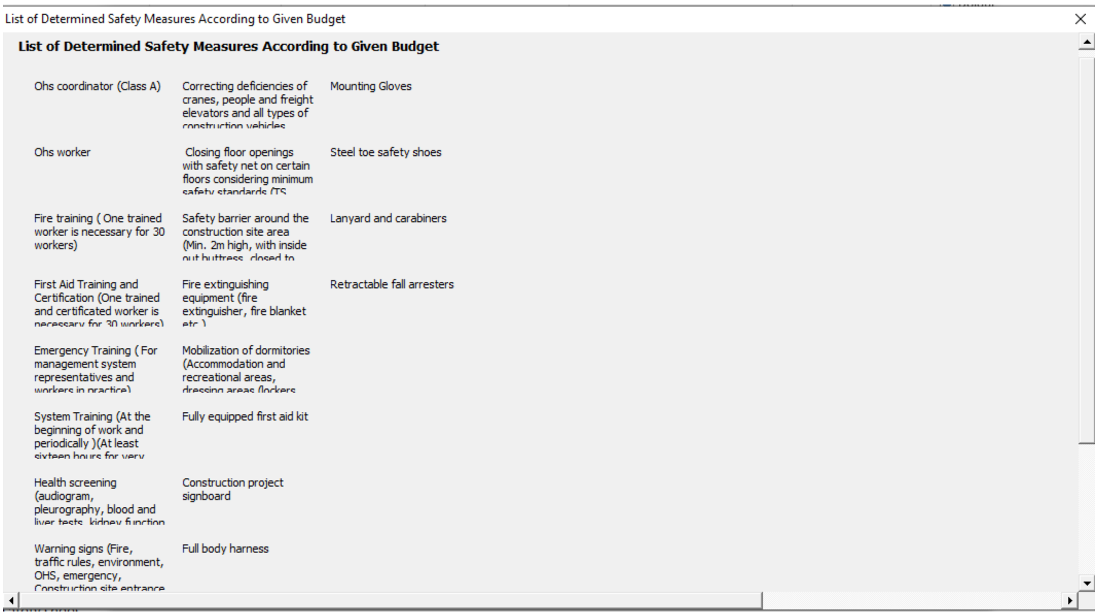


Figure 7.12. List of Determined Safety Measures According to Given Budget

CHAPTER 8

CASE STUDY

8.1. General

A case study was conducted to evaluate the usability of the proposed excel tool according to the described methodology and to assess whether it reached the specified aims. The State Hydraulic Works Directorate New HQ Building Project is chosen for this case study. The project is located in Ankara/Turkey. It has 101,625 m² total construction area, and within the scope of the project, Headquarters for State Hydraulic Works, a convention centre, a staff mess hall, an IT service building, a heating centre and closed/open car parks together with all associated infrastructure and landscaping works will be performed. The Employer is “General Directorate of State Hydraulic Works,” and the contractor is “Siyahkalem Mühendislik İnşaat Sanayi ve Ticaret A.Ş.”. The project started in 2016 and will be completed in 2020 according to the contract, and the total contract price of the project is 110,840,000 TL.

Four technical personnel participated in the case study. These are respectively, site manager, construction field engineer, OHS coordinator (A-class) and safety expert (B-class). They participated in the initial risk evaluation process separately, but the secondary and the final risk evaluation process was carried out by taking the opinions of other participants under the supervision of the OHS coordinator. Therefore, there was four participants shown in the initial risk evaluation process but one participant in the secondary and the final risk evaluation process.

A brief explanation about developed excel tool was given to these four participants before they started to use the tool. According to this meeting, preliminary work was carried out by the users, and then these works were transferred to the developed excel tool. The case study was completed in two weeks, taking into consideration the workload of the users.

8.2. Application of the Developed Tool to a Real Construction Project

Developed excel tool has a simple user interface and managed from the home page shown in Figure 8.1. First, the form for the initial risk evaluation was filled with these four participants. One of the forms is shown in Figure 8.2 and Figure 8.3 as an example. After all the participant finished filling the form, the initial risk evaluation process was performed. Initial risk index and initial risk ranking were calculated and shown, respectively, in Figure 8.4 and Figure 8.5.

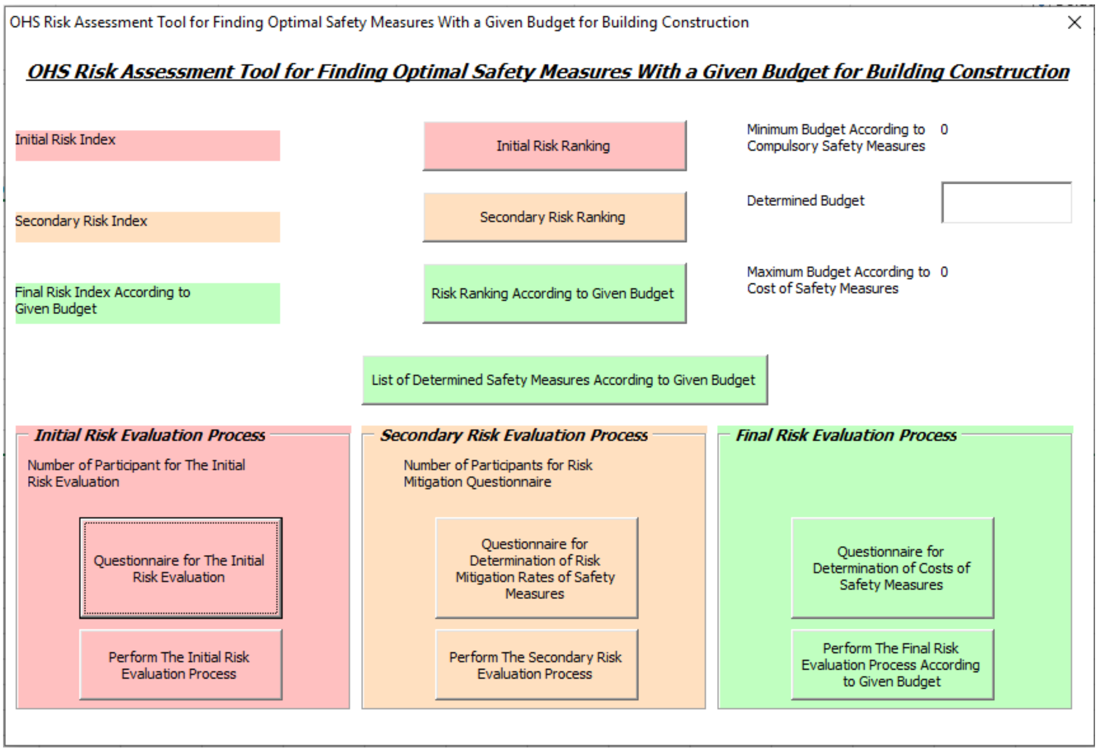
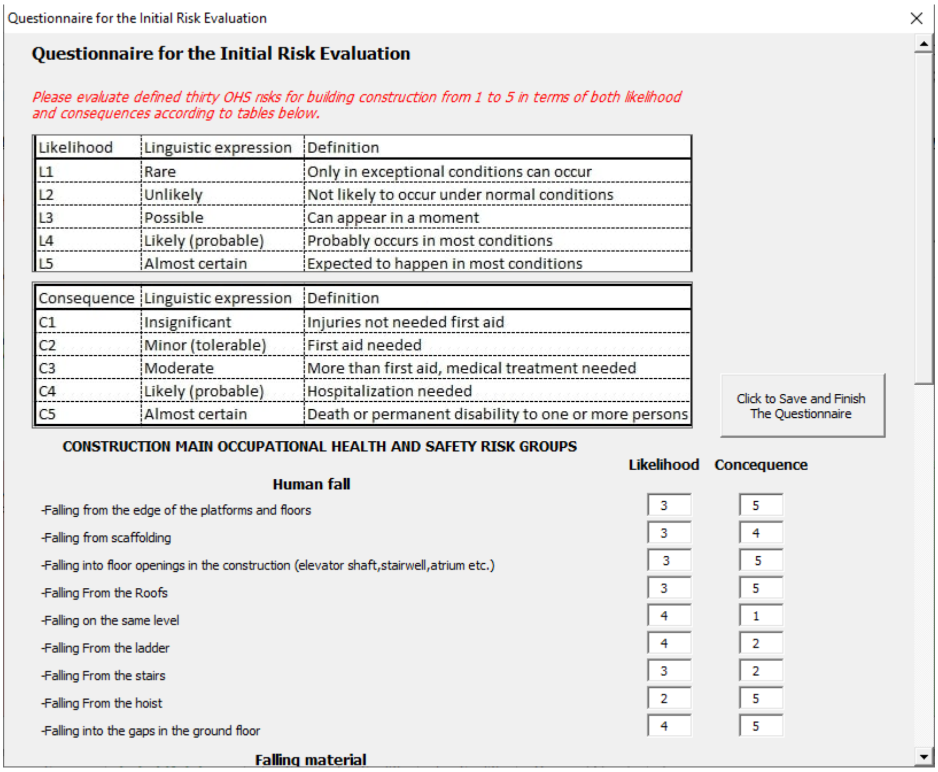


Figure 8.1. Home Page of the Developed Excel Tool


Questionnaire for the Initial Risk Evaluation

Questionnaire for the Initial Risk Evaluation

Please evaluate defined thirty OHS risks for building construction from 1 to 5 in terms of both likelihood and consequences according to tables below.

Likelihood	Linguistic expression	Definition
L1	Rare	Only in exceptional conditions can occur
L2	Unlikely	Not likely to occur under normal conditions
L3	Possible	Can appear in a moment
L4	Likely (probable)	Probably occurs in most conditions
L5	Almost certain	Expected to happen in most conditions

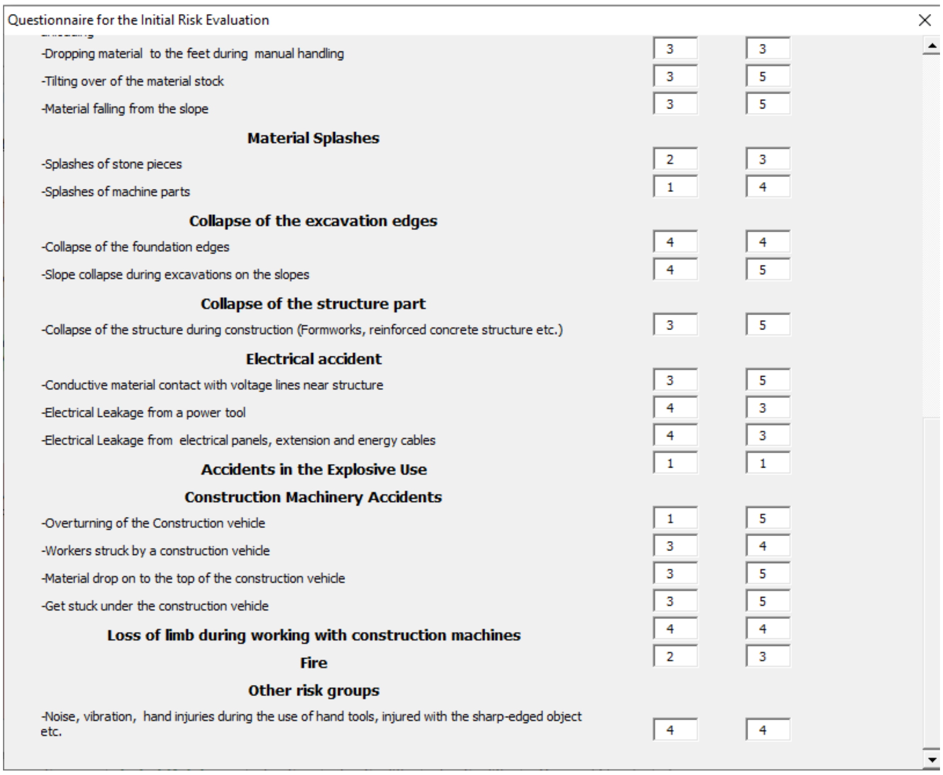
Consequence	Linguistic expression	Definition
C1	Insignificant	Injuries not needed first aid
C2	Minor (tolerable)	First aid needed
C3	Moderate	More than first aid, medical treatment needed
C4	Likely (probable)	Hospitalization needed
C5	Almost certain	Death or permanent disability to one or more persons

Click to Save and Finish The Questionnaire

CONSTRUCTION MAIN OCCUPATIONAL HEALTH AND SAFETY RISK GROUPS

	Likelihood	Concequence
Human fall		
-Falling from the edge of the platforms and floors	3	5
-Falling from scaffolding	3	4
-Falling into floor openings in the construction (elevator shaft,stairwell,atrium etc.)	3	5
-Falling From the Roofs	3	5
-Falling on the same level	4	1
-Falling From the ladder	4	2
-Falling From the stairs	3	2
-Falling From the hoist	2	5
-Falling into the gaps in the ground floor	4	5
Falling material		

Figure 8.2. Filling the Form for the Initial Risk Evaluation


Questionnaire for the Initial Risk Evaluation

-Dropping material to the feet during manual handling	3	3
-Tilting over of the material stock	3	5
-Material falling from the slope	3	5
Material Splashes		
-Splashes of stone pieces	2	3
-Splashes of machine parts	1	4
Collapse of the excavation edges		
-Collapse of the foundation edges	4	4
-Slope collapse during excavations on the slopes	4	5
Collapse of the structure part		
-Collapse of the structure during construction (Formworks, reinforced concrete structure etc.)	3	5
Electrical accident		
-Conductive material contact with voltage lines near structure	3	5
-Electrical Leakage from a power tool	4	3
-Electrical Leakage from electrical panels, extension and energy cables	4	3
Accidents in the Explosive Use	1	1
Construction Machinery Accidents		
-Overturning of the Construction vehicle	1	5
-Workers struck by a construction vehicle	3	4
-Material drop on to the top of the construction vehicle	3	5
-Get stuck under the construction vehicle	3	5
Loss of limb during working with construction machines	4	4
Fire	2	3
Other risk groups		
-Noise, vibration, hand injuries during the use of hand tools, injured with the sharp-edged object etc.	4	4

Figure 8.3. Filling the Form for the Initial Risk Evaluation (Continued)

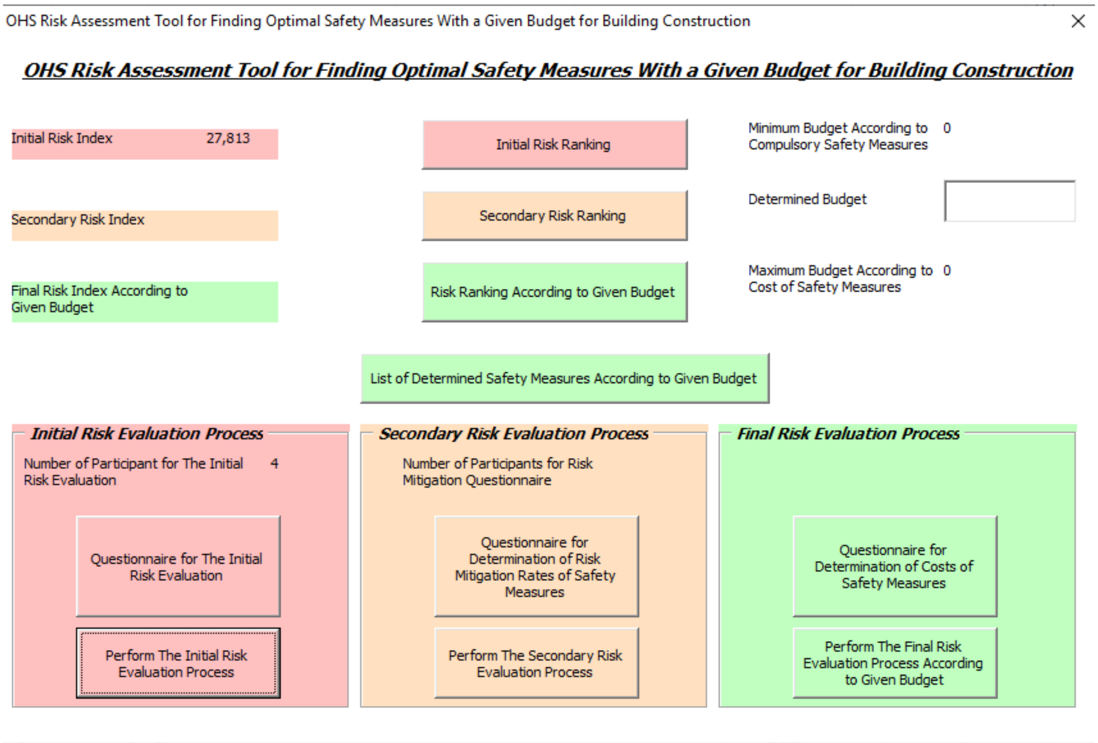


Figure 8.4. Finding the Initial Risk Index in the Case Study


Initial Risk Ranking

Initial Risk Ranking

Falling From the Roofs	1	Get stuck under the construction vehicle	0,58	Falling on the same level	0,25
Falling into floor openings in the construction (elevator shaft,stairwell,atrium etc.)	0,76	electrical Leakage from a power tool	0,53	Splashes of stone pieces	0,25
Falling into the gaps in the ground floor	0,76	electrical Leakage from a electrical panels, extension and energy cables	0,53	Material falling from the slope	0,18
Material falling from the upper floors	0,76	Other risk groups hand injuries during the use of hand tools, injured with the sharp-edged object etc.	0,53	overturning of the Construction vehicle	0,18
Falling From the hoist	0,75	slope collapse during excavations on the slopes	0,5	loss of limb during working with construction machines	0,16
Falling from scaffolding	0,65	Conductive material contact with voltage lines near structure	0,38	Fire	0,14
Material falling from the vehicle (crane, truck, hoist, backhoe loader etc.) during loading and unloading	0,65	Falling from the edge of the platforms and floors	0,37	Splashes of machine parts	0,11
collapse of the foundation edges	0,58	Falling From the ladder	0,37	Falling From the stairs	0,08
Collapse of the structure during construction (Formworks, reinforced concrete structure etc.)	0,58	material drop on to the top of the construction vehicle	0,37	dropping material to the feet during manual handling	0,07
workers struck by a construction vehicle	0,58	tilting over of the material stock	0,3	Accidents in the Explosive Use	0

Figure 8.5. Finding the Initial Risk Ranking in the Case Study

After the initial risk evaluation process was over, the secondary risk evaluation process was carried out by taking the opinions of other participants under the supervision of the OHS coordinator. For the secondary risk evaluation process, form for determination of risk mitigation rates of safety measures was filled only by the OHS coordinator. This form consists of nine pages, and these are shown respectively in Figure 8.6 to Figure 8.14.

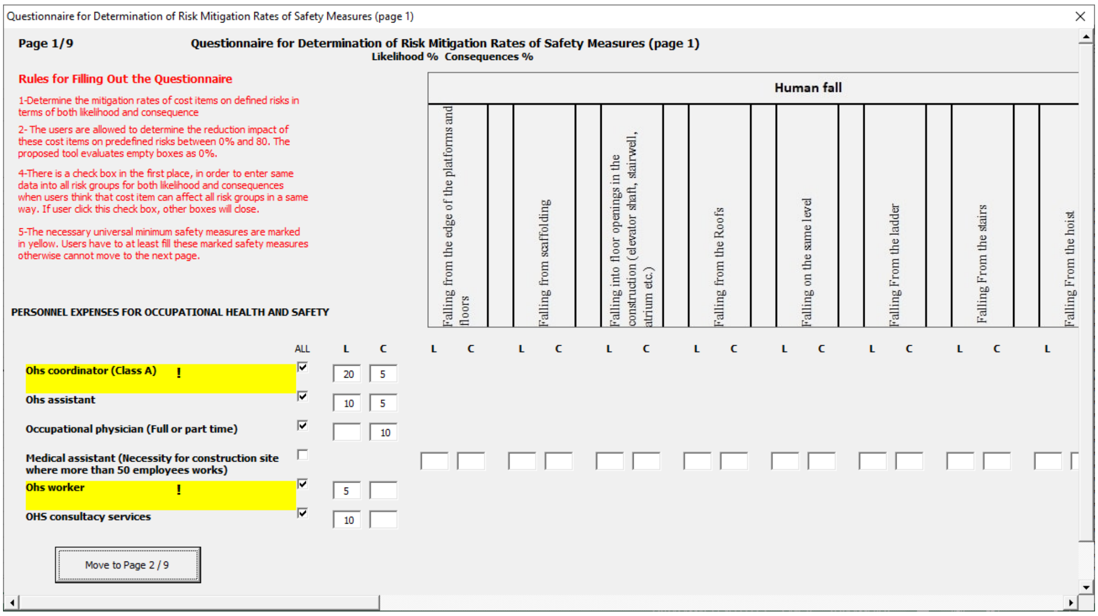


Figure 8.6. Filling the Form for Determination of Risk Mitigation Rates of Safety Measures (page 1)

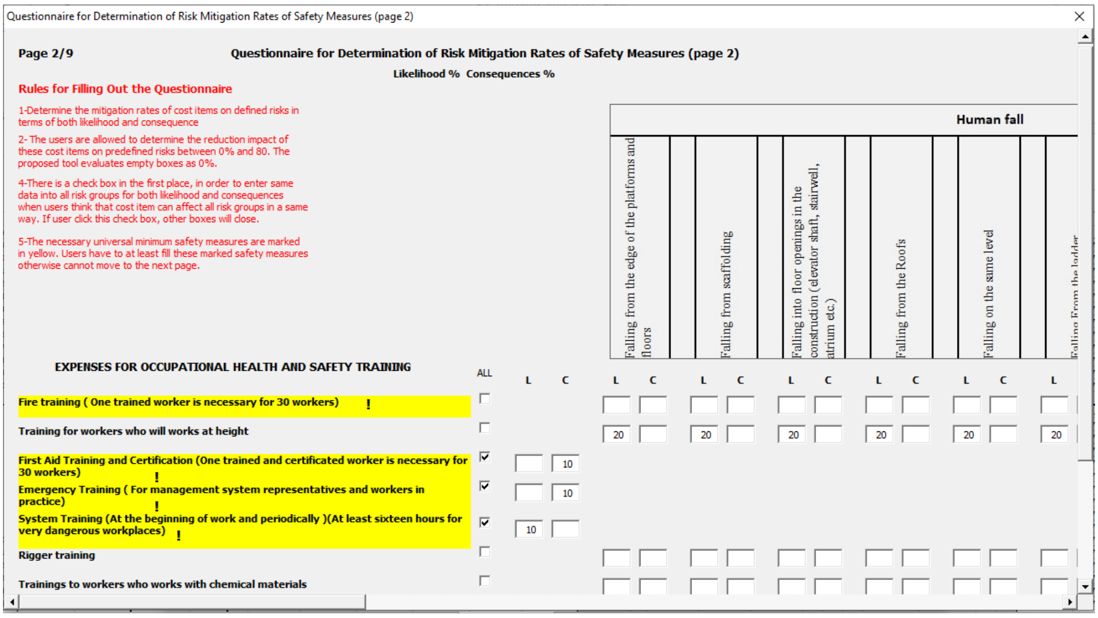


Figure 8.7. Filling the Form for Determination of Risk Mitigation Rates of Safety Measures (page 2)

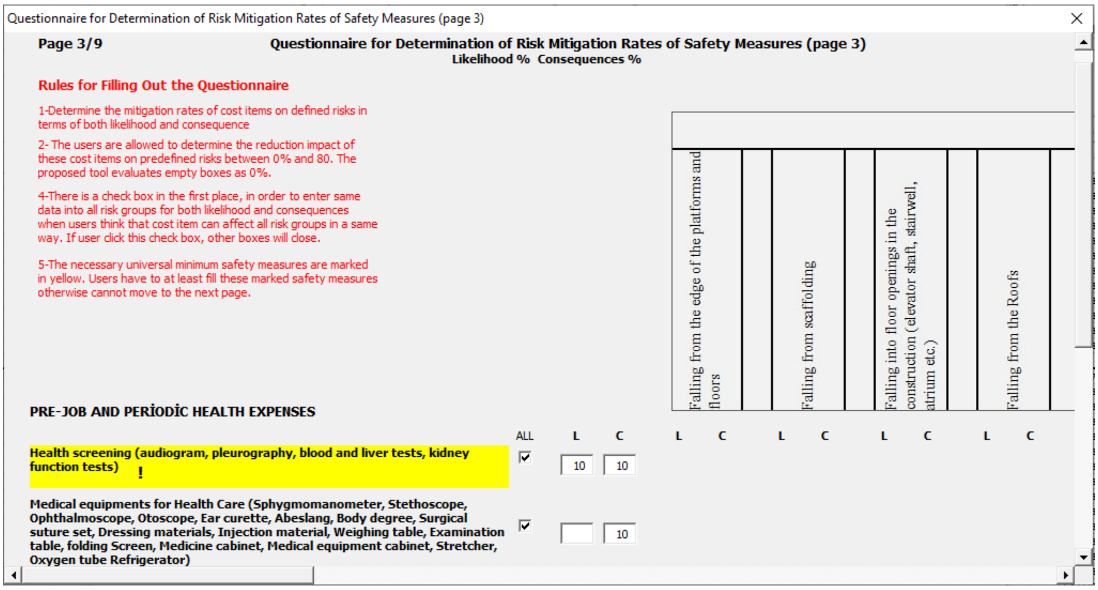


Figure 8.8. Filling the Form for Determination of Risk Mitigation Rates of Safety Measures (page 3)

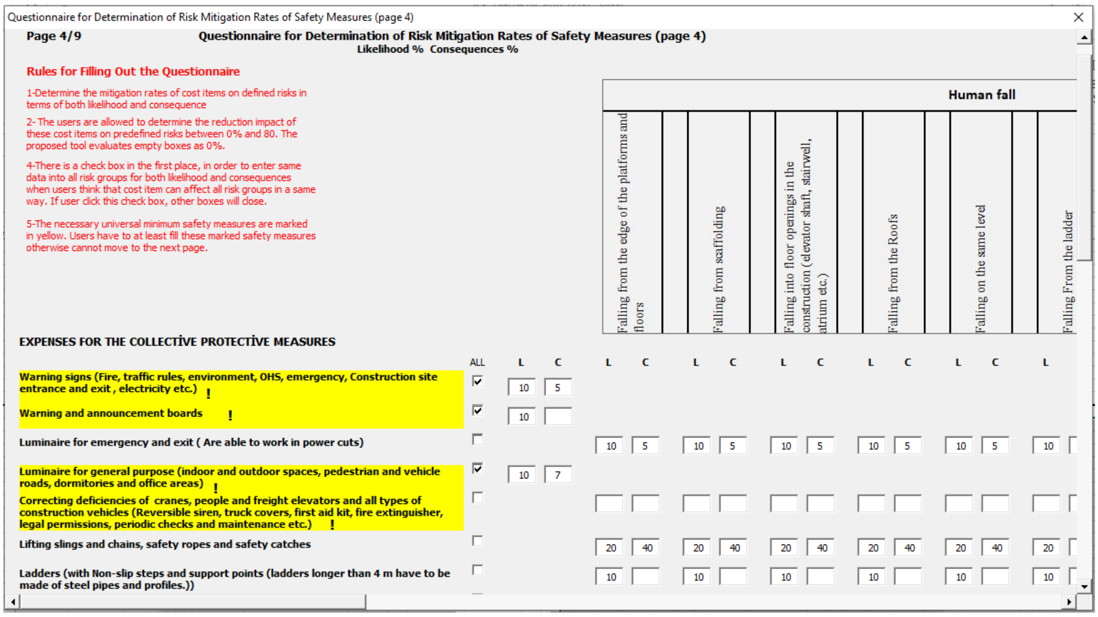


Figure 8.9. Filling the Form for Determination of Risk Mitigation Rates of Safety Measures (page 4)

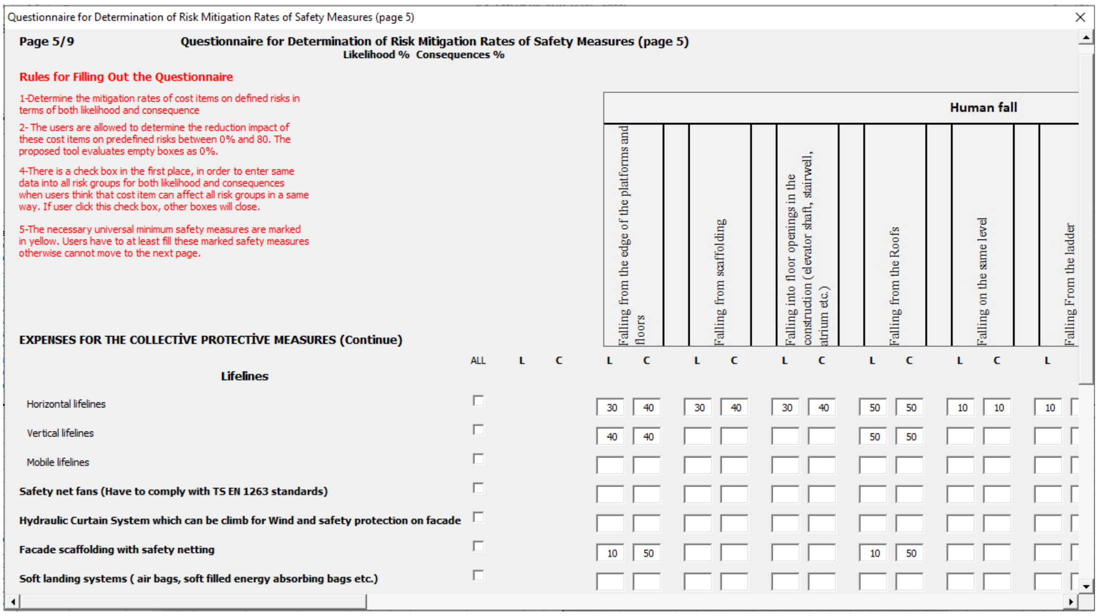


Figure 8.10. Filling the Form for Determination of Risk Mitigation Rates of Safety Measures (page 5)

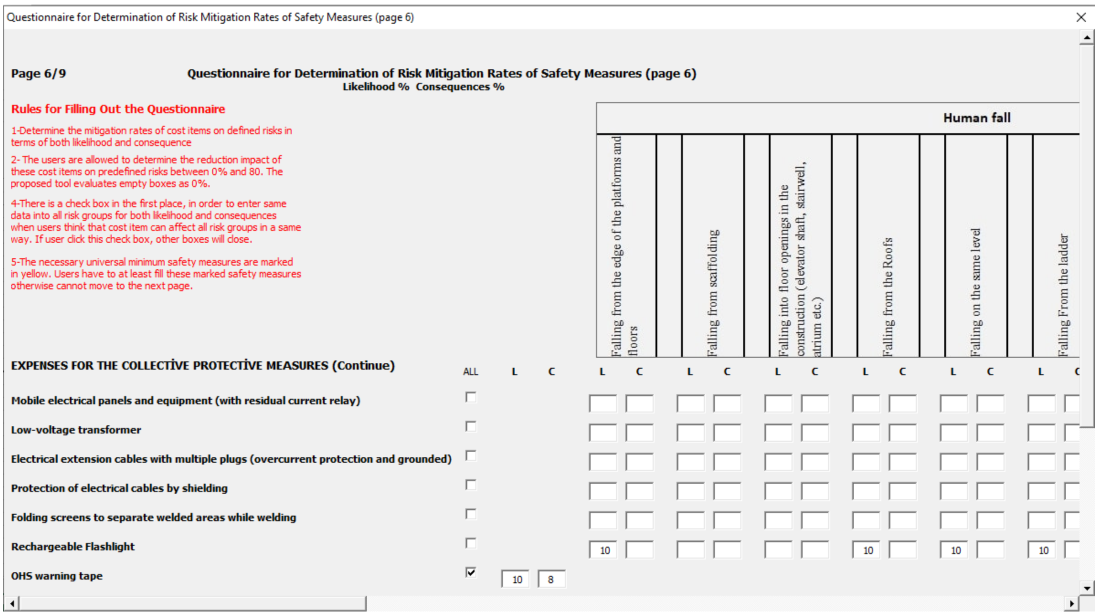


Figure 8.11. Filling the Form for Determination of Risk Mitigation Rates of Safety Measures (page 6)

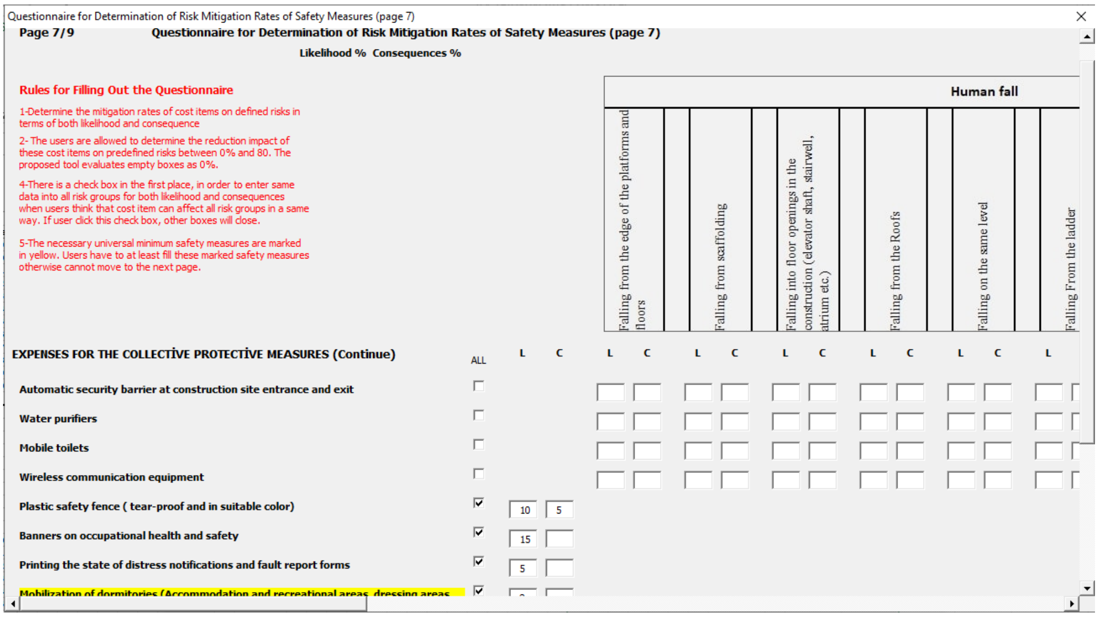
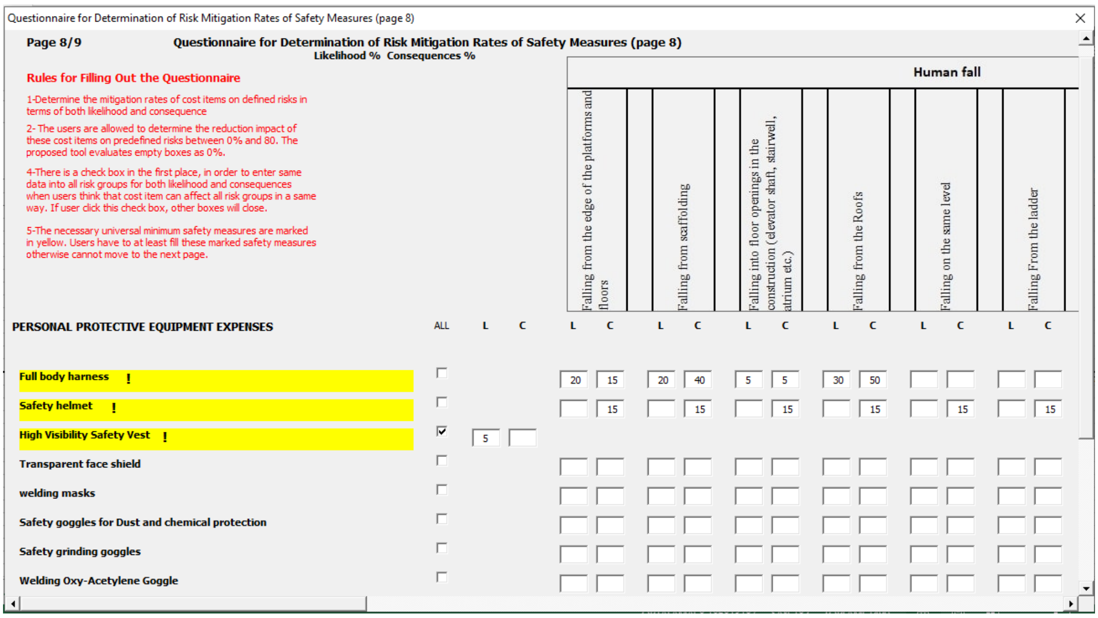


Figure 8.12. Filling the Form for Determination of Risk Mitigation Rates of Safety Measures (page 7)


Questionnaire for Determination of Risk Mitigation Rates of Safety Measures (page 8)

Page 8/9 Questionnaire for Determination of Risk Mitigation Rates of Safety Measures (page 8)
Likelihood % Consequences %

Rules for Filling Out the Questionnaire

1-Determine the mitigation rates of cost items on defined risks in terms of both likelihood and consequence

2- The users are allowed to determine the reduction impact of these cost items on predefined risks between 0% and 80. The proposed tool evaluates empty boxes as 0%.

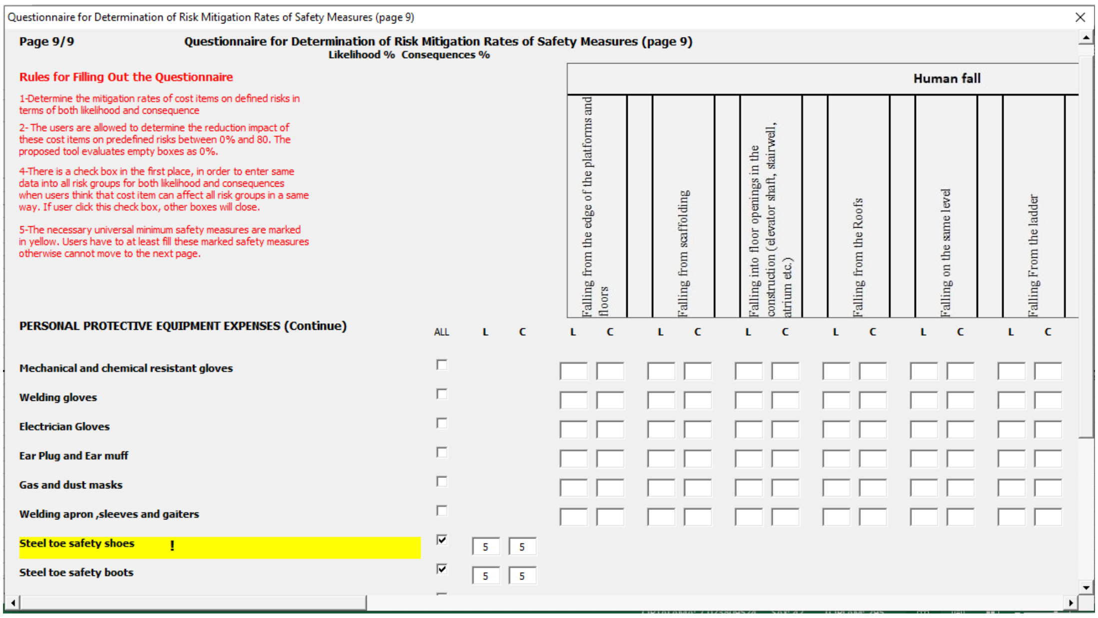
4-There is a check box in the first place, in order to enter same data into all risk groups for both likelihood and consequences when users think that cost item can affect all risk groups in a same way. If user click this check box, other boxes will close.

5-The necessary universal minimum safety measures are marked in yellow. Users have to at least fill these marked safety measures otherwise cannot move to the next page.

Human fall

PERSONAL PROTECTIVE EQUIPMENT EXPENSES	ALL	L	C	Falling from the edge of the platforms and floors L	C	Falling from scaffolding L	C	Falling into floor openings in the construction (elevator shaft, stairwell, atrium etc.) L	C	Falling from the Roofs L	C	Falling on the same level L	C	Falling From the ladder L	C
Full body harness !				20	15	20	40	5	5	30	50				
Safety helmet !					15		15		15		15		15		15
High Visibility Safety Vest !	☑	5													
Transparent face shield															
welding masks															
Safety goggles for Dust and chemical protection															
Safety grinding goggles															
Welding Oxy-Acetylene Goggle															

Figure 8.13. Filling the Form for Determination of Risk Mitigation Rates of Safety Measures (page 8)


Questionnaire for Determination of Risk Mitigation Rates of Safety Measures (page 9)

Page 9/9 Questionnaire for Determination of Risk Mitigation Rates of Safety Measures (page 9)
Likelihood % Consequences %

Rules for Filling Out the Questionnaire

1-Determine the mitigation rates of cost items on defined risks in terms of both likelihood and consequence

2- The users are allowed to determine the reduction impact of these cost items on predefined risks between 0% and 80. The proposed tool evaluates empty boxes as 0%.

4-There is a check box in the first place, in order to enter same data into all risk groups for both likelihood and consequences when users think that cost item can affect all risk groups in a same way. If user click this check box, other boxes will close.

5-The necessary universal minimum safety measures are marked in yellow. Users have to at least fill these marked safety measures otherwise cannot move to the next page.

Human fall

PERSONAL PROTECTIVE EQUIPMENT EXPENSES (Continue)	ALL	L	C	Falling from the edge of the platforms and floors L	C	Falling from scaffolding L	C	Falling into floor openings in the construction (elevator shaft, stairwell, atrium etc.) L	C	Falling from the Roofs L	C	Falling on the same level L	C	Falling From the ladder L	C
Mechanical and chemical resistant gloves															
Welding gloves															
Electrician Gloves															
Ear Plug and Ear muff															
Gas and dust masks															
Welding apron ,sleeves and gaiters															
Steel toe safety shoes !	☑	5	5												
Steel toe safety boots	☑	5	5												

Figure 8.14. Filling the Form for Determination of Risk Mitigation Rates of Safety Measures (page 9)

After the OHS coordinator finished filling the form, the secondary risk evaluation process was performed. Secondary risk index and secondary risk ranking were calculated and shown, respectively, in Figure 8.15 and Figure 8.16.

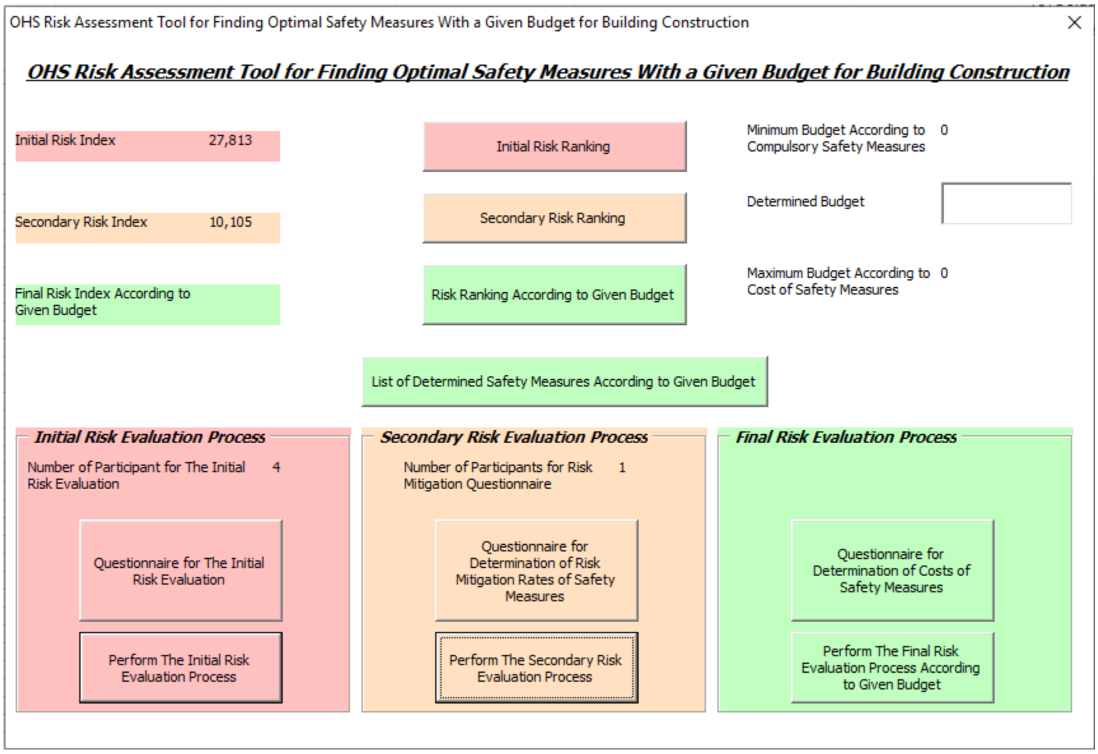


Figure 8.15. Finding the Secondary Risk Index in the Case Study


Secondary Risk Ranking

Secondary Risk Ranking

collapse of the foundation edges	1	Splashes of stone pieces	0,71	Falling into the gaps in the ground floor	0,36
Collapse of the structure during construction (Formworks, reinforced concrete structure etc.)	1	Conductive material contact with voltage lines near structure	0,64	Falling From the hoist	0,36
workers struck by a construction vehicle	0,97	Material falling from the slope	0,63	Material falling from the upper floors	0,33
Get stuck under the construction vehicle	0,94	overturning of the Construction vehicle	0,63	Falling into floor openings in the construction (elevator shaft,stairwell,atrium etc.)	0,25
slope collapse during excavations on the slopes	0,93	loss of limb during working with construction machines	0,61	Falling From the ladder	0,23
Material falling from the vehicle (crane, truck, hoist, backhoe loader etc.) during loading and unloading	0,87	Splashes of machine parts	0,6	Falling on the same level	0,23
material drop on to the top of the construction vehicle	0,79	dropping material to the feet during manual handling	0,55	Falling From the stairs	0,14
electrical Leakage from a power tool	0,75	Accidents in the Explosive Use	0,52	Falling from scaffolding	0,1
electrical Leakage from a electrical panels, extension and energy cables	0,75	Other risk groups hand injuries during the use of hand tools, injured with the sharp-edged object	0,52	Falling From the Roofs	0,02
tilting over of the material stock	0,73	Fire	0,47	Falling from the edge of the platforms and floors	0

Figure 8.16. Finding the Secondary Risk Ranking in the Case Study

After the secondary risk evaluation process was over, the final risk evaluation process was carried out. For the final risk evaluation process, form for determination of costs of safety measures was filled by OHS coordinator. This form consists of five windows on a single page, and these are shown respectively in Figure 8.17 to Figure 8.21.

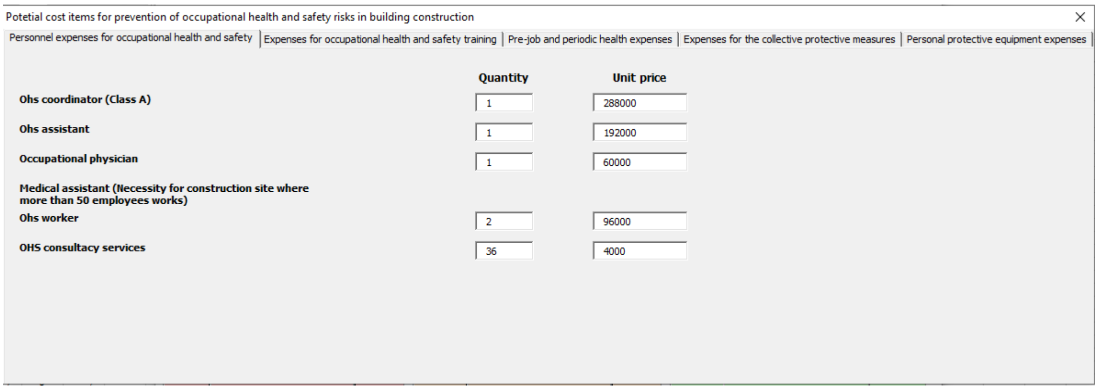


Figure 8.17. Filling the Form for Determination of Costs of Safety Measures (1st window)

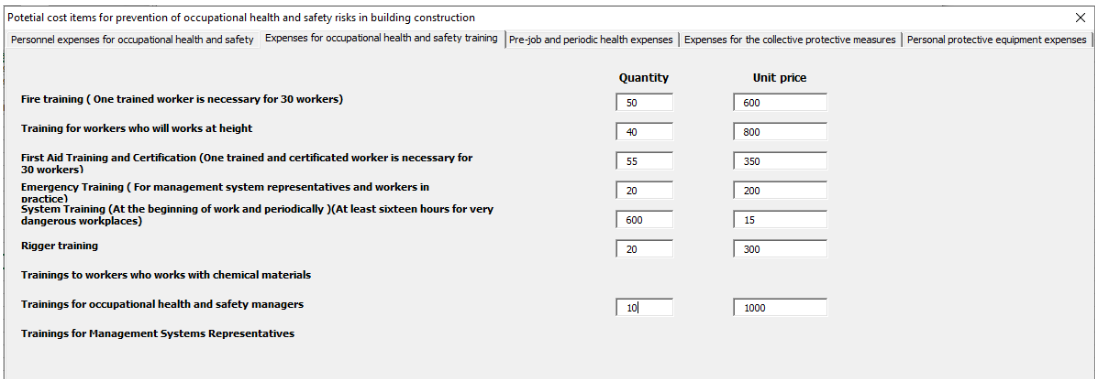


Figure 8.18. Filling the Form for Determination of Costs of Safety Measures (2nd window)

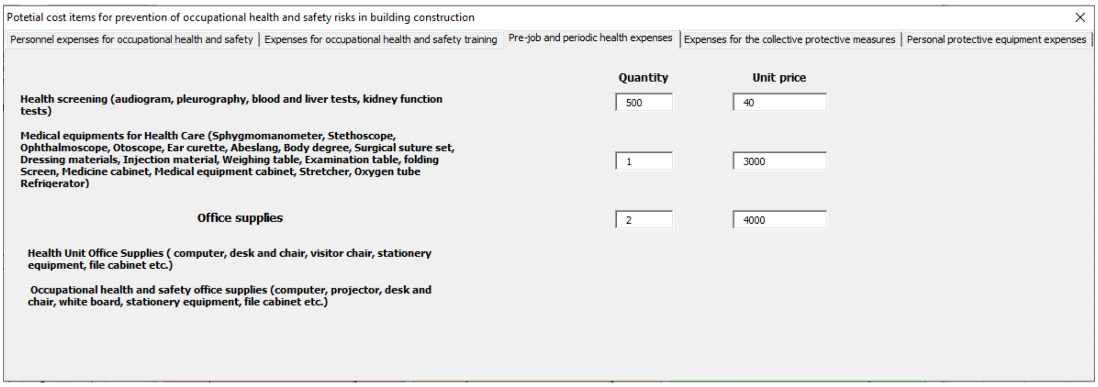


Figure 8.19. Filling the Form for Determination of Costs of Safety Measures (3rd window)

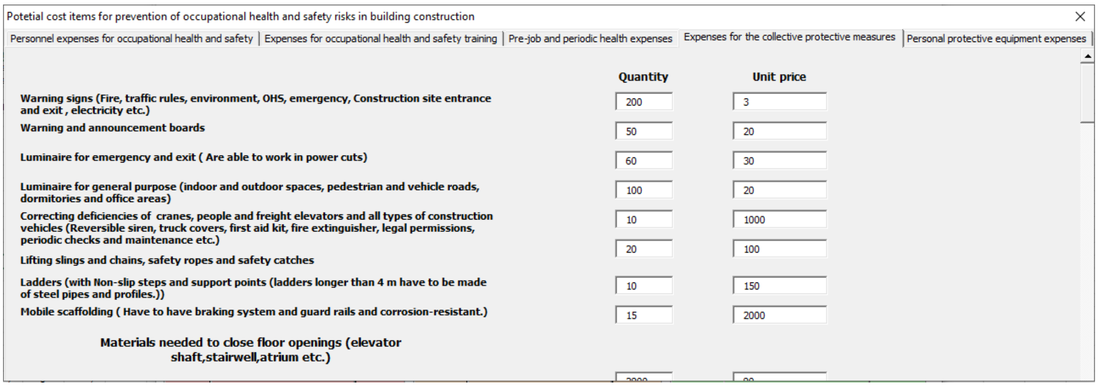


Figure 8.20. Filling the Form for Determination of Costs of Safety Measures (4th window)

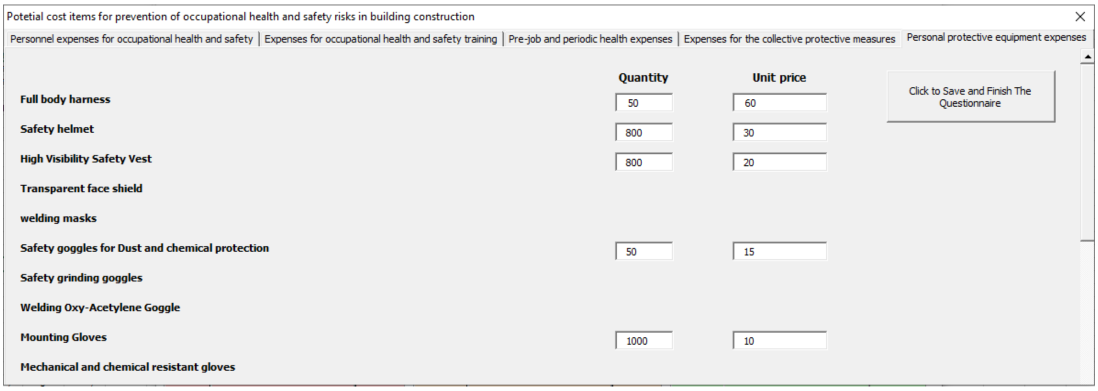


Figure 8.21. Filling the Form for Determination of Costs of Safety Measures (5th window)

After OHS coordinator finished filling the form, the minimum budget according to compulsory safety measures and the maximum budget according to the cost of safety measures are shown on the main page. A budget needs to be determined that ranged between these min and max value by OHS coordinator or contractor. For this project, the determined budget for OHS was 2,200,000 TL. According to the entered data, min budget found as 1,638,700 TL and max budget found as 2,706,600 TL. The final risk evaluation process was performed according to the determined budget. Final risk index, final risk ranking, and list of determined optimal safety measures according to the given budget were calculated and shown respectively in Figure 8.22 to 8.25.

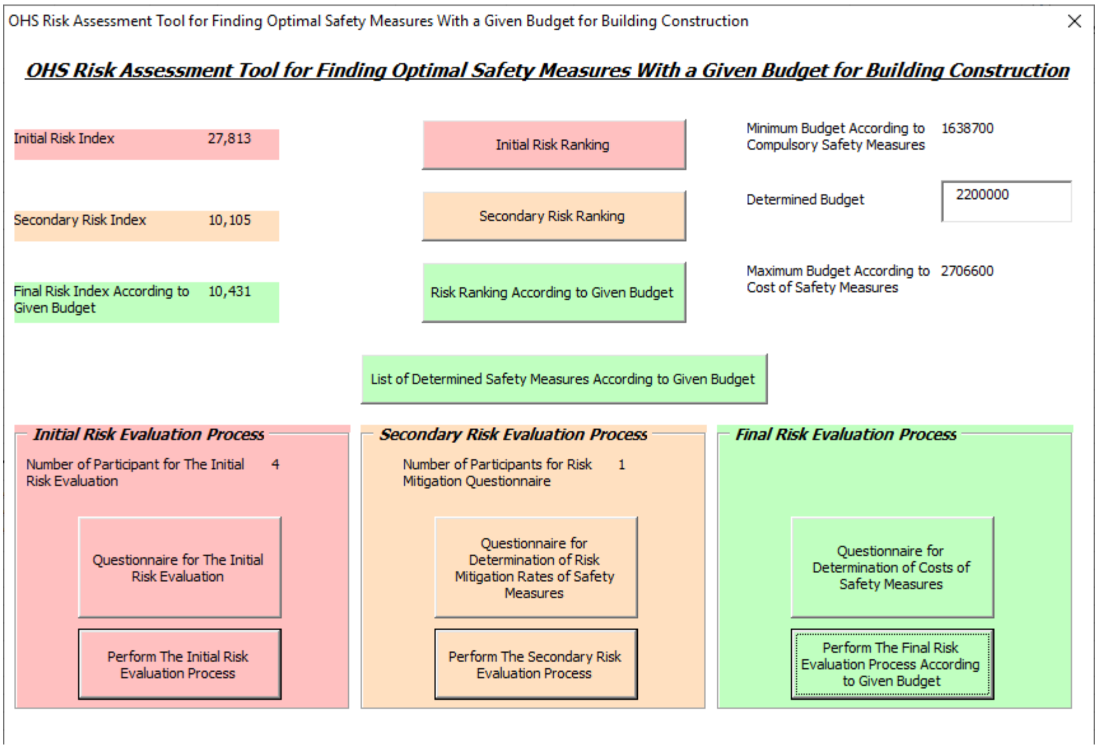
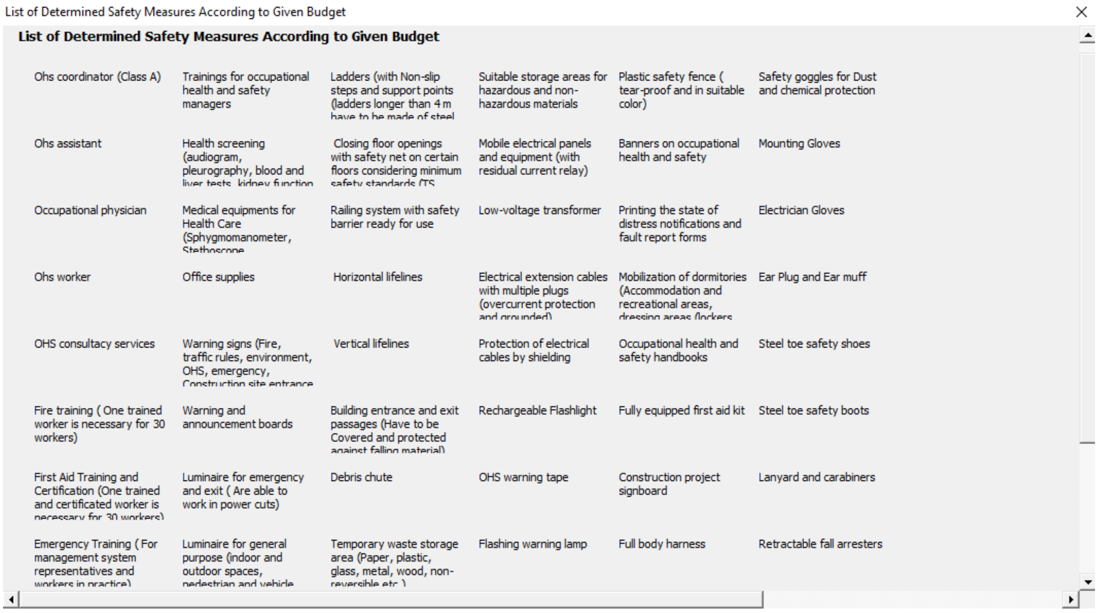


Figure 8.22. Finding the Final Risk Index and Determined the OHS Budget in the Case Study

Figure 8.23. Finding the Final Risk Ranking in the Case Study

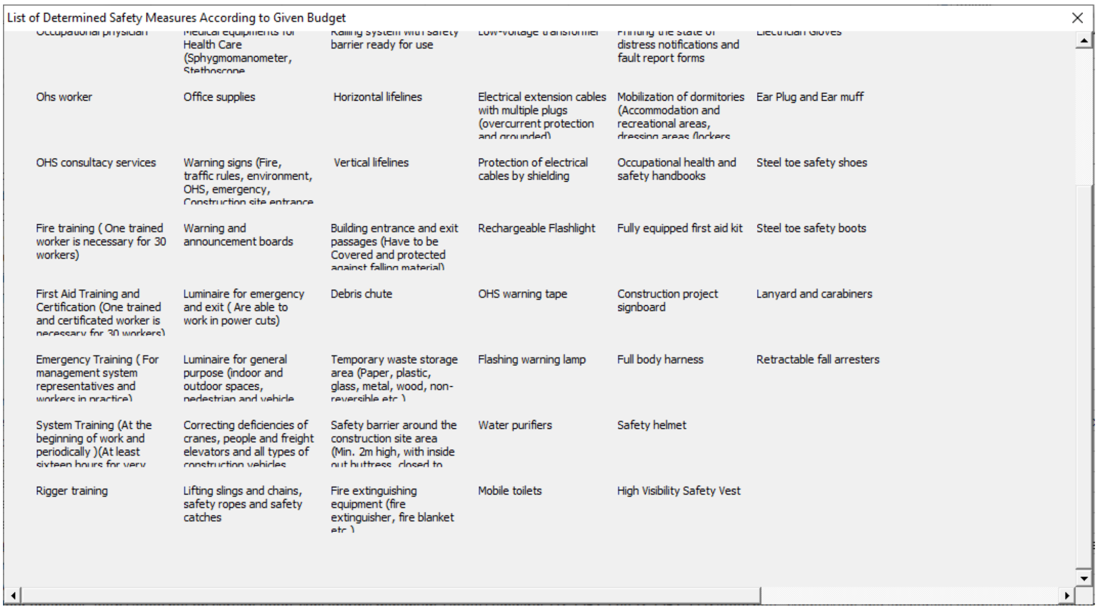


List of Determined Safety Measures According to Given Budget

List of Determined Safety Measures According to Given Budget

Ohs coordinator (Class A)	Trainings for occupational health and safety managers	Ladders (with Non-slip steps and support points (ladders longer than 4 m have to be made of steel	Suitable storage areas for hazardous and non-hazardous materials	Plastic safety fence (tear-proof and in suitable color)	Safety goggles for Dust and chemical protection
Ohs assistant	Health screening (audiogram, pleurography, blood and liver tests, kidney function	Closing floor openings with safety net on certain floors considering minimum safety standards (TS	Mobile electrical panels and equipment (with residual current relay)	Banners on occupational health and safety	Mounting Gloves
Occupational physician	Medical equipments for Health Care (Sphygmomanometer, Stethoscope	Railing system with safety barrier ready for use	Low-voltage transformer	Printing the state of distress notifications and fault report forms	Electrician Gloves
Ohs worker	Office supplies	Horizontal lifelines	Electrical extension cables with multiple plugs (overcurrent protection and grounded)	Mobilization of dormitories (Accommodation and recreational areas, dressing areas (lockers	Ear Plug and Ear muff
OHS consultacy services	Warning signs (Fire, traffic rules, environment, OHS, emergency, Construction site entrance	Vertical lifelines	Protection of electrical cables by shielding	Occupational health and safety handbooks	Steel toe safety shoes
Fire training (One trained worker is necessary for 30 workers)	Warning and announcement boards	Building entrance and exit passages (Have to be Covered and protected against falling material)	Rechargeable Flashlight	Fully equipped first aid kit	Steel toe safety boots
First Aid Training and Certification (One trained and certificated worker is necessary for 30 workers)	Luminaire for emergency and exit (Are able to work in power cuts)	Debris chute	OHS warning tape	Construction project signboard	Lanyard and carabiners
Emergency Training (For management system representatives and workers in practice)	Luminaire for general purpose (indoor and outdoor spaces, pedestrian and vehicle	Temporary waste storage area (Paper, plastic, glass, metal, wood, non-reversible etc.)	Flashing warning lamp	Full body harness	Retractable fall arresters

Figure 8.24. List of Determined Safety Measures According to Given Budget



List of Determined Safety Measures According to Given Budget

Occupational physician	Medical equipments for Health Care (Sphygmomanometer, Stethoscope	Railing system with safety barrier ready for use	Low-voltage transformer	Printing the state of distress notifications and fault report forms	Electrician Gloves
Ohs worker	Office supplies	Horizontal lifelines	Electrical extension cables with multiple plugs (overcurrent protection and grounded)	Mobilization of dormitories (Accommodation and recreational areas, dressing areas (lockers	Ear Plug and Ear muff
OHS consultacy services	Warning signs (Fire, traffic rules, environment, OHS, emergency, Construction site entrance	Vertical lifelines	Protection of electrical cables by shielding	Occupational health and safety handbooks	Steel toe safety shoes
Fire training (One trained worker is necessary for 30 workers)	Warning and announcement boards	Building entrance and exit passages (Have to be Covered and protected against falling material)	Rechargeable Flashlight	Fully equipped first aid kit	Steel toe safety boots
First Aid Training and Certification (One trained and certificated worker is necessary for 30 workers)	Luminaire for emergency and exit (Are able to work in power cuts)	Debris chute	OHS warning tape	Construction project signboard	Lanyard and carabiners
Emergency Training (For management system representatives and workers in practice)	Luminaire for general purpose (indoor and outdoor spaces, pedestrian and vehicle	Temporary waste storage area (Paper, plastic, glass, metal, wood, non-reversible etc.)	Flashing warning lamp	Full body harness	Retractable fall arresters
System Training (At the beginning of work and periodically)(At least sixteen hours for very	Correcting deficiencies of cranes, people and freight elevators and all types of construction vehicles	Safety barrier around the construction site area (Min. 2m high, with inside out buttress, closed to	Water purifiers	Safety helmet	
Rigger training	Lifting slings and chains, safety ropes and safety catches	Fire extinguishing equipment (fire extinguisher, fire blanket etc.)	Mobile toilets	High Visibility Safety Vest	

Figure 8.25. List of Determined Safety Measures According to Given Budget (Continued)

8.3. Findings from the Case Study

As a result of the case study, the initial risk index was found as 27.813. The most critical risk to avoid is observed as "Falling from the roof". On the other hand, the least important risk was found as "Accident in the explosive use". According to the risk assessment team, these results were found as realistic. Because they told that, considering the height of the building, there is a wide roof area in this project and no explosive materials were used in the project. The secondary risk index was found as 10.105. It means that this is the minimum risk value that can be achieved when all identified OHS prevention items are achieved. According to the secondary risk ranking, the level of the risk of falling from the roof was reduced to the minimum level. For this project, the determined budget for OHS was 2,200,000 TL. According to the entered data, min possible budget found as 1,638,700 TL and max possible budget found as 2,706,600 TL. As a result of the final risk evaluation process according to the given budget, the risk index was found as 10.431. The resulting risk index was very close to the min risk index. The risk index can be within the range "2. 37" and "71.97" according to developed excel tool, and it was left to the user to interpret the resulting risk index whether it is in the acceptable level or not. Because it is known that safety professionals use subjective linguistic terms for assessing risks instead of definite judgments, and they have different risk acceptance criteria. Also, there is no defined, acceptable risk acceptance criterion in any legal legislation and regulation.

According to the risk assessment team, the calculated final risk index was at an acceptable level with the determined budget. Therefore, the results were found realistic by the risk assessment team. When the total contract price of the project is compared with the determined OHS budget, it can be seen that determined OHS budget as almost %2 of the total contract price. Where defined OHS budget is 2,200,000 TL and the total contract price of the project is 110,840,000 TL.

CHAPTER 9

CONCLUSIONS

The construction sector is a manpower dominated sector, and it has higher rate of work-related accidents compared to other sectors due to difficult working conditions, long working hours and relatively lower qualification of workers. Therefore, occupational health and safety is an obligation in such a human-based industry, and OHS measures, investments on accident prevention, legislation and regulations for the protection of workers from the OHS risks of the construction sector is very important. Within this scope, in Turkey, the latest version of OHS law no.6331 has been put in place by the Ministry of Labor and Social Security, in order to provide and maintain OHS standards on construction process. The most important item that comes into force with this law is, employers are obliged to perform a risk assessment regardless of their activity, size or structure. But, when today's competitive conditions are considered, some contractors don't want to spend their limited time and resources for risk assessment process, and they ignore many important measures during the construction practice to minimize total construction costs due to their concern of profitability. However, it is possible to achieve profitability while providing safe working environment by developing a safety risk assessment process in accordance with today's requirements.

In this thesis, a novel qualitative OHS risk management method for finding optimal safety measures with a given budget for building construction by using FTOPSIS was developed. Developed OHS risk management method is based on qualitative data that comes from subjective safety expert judgements. These judgements are linguistic variables and contain lots of subjectivity due to the level of knowledge and experience of safety professionals about risks in construction and their likelihood and consequences. Fuzzy TOPSIS method was adapted and integrated into this method to cope with subjectivity and uncertainty of safety expert judgments. With the help of fuzzy theory, linguistic variables were translated into numerical values as likelihood and consequence of the identified risk. Then, with the help of FTOPSIS, determined risks were evaluated and ranked according to these fuzzy numbers. The developed method also finds optimal safety measures for a given budget based on risk assessment made through a mixed-integer nonlinear programming model. Also, to implement the developed risk management method and to increase its use in practice, a MS Excel Tool has been created using VBA (Visual Basic for Applications).

The main contributions of this thesis for both literature, construction companies and OHS can be listed as follows:

- A detailed list of OHS risks for building construction was prepared based on the literature review and the experience of safety experts. The list consists of 30 OHS risks under ten main OHS risk group. Also, there is a heading as other risk groups (Which contains noise, vibration, hand injuries during the use of hand tools, injured with the sharp-edged object etc.). These safety risks are not referred very often in the literature by researchers. Therefore, they were grouped as other risk groups under this main heading in consultation with security experts.
- The list of potential cost items for prevention of occupational health and safety risks in building constructions were determined according to both literature review, market research, experiences of safety experts and OHS law no.6331. The list consists of 94 potential cost items to reduce occupational health and safety risks in building constructions under five main headings. It is aimed to provide convenience to the users by presenting this predetermined list.
- To maintain profitability for contractors while providing a safe working environment, safety risk management method was developed in accordance with today's requirements. So, with this method, contractors will be able to

carry out the long-term risk assessment process in less time. Normally the safety risk assessment process may take weeks or even months depending on the construction process.

- The proposed method can be applied anywhere in the world, although it was prepared considering the OHS laws in Turkey. Because, the prepared list for both potential risks and cost items are also based on universal literature sources. The proposed risk management method can be used even if current laws change.

- The proposed method allows the risk assessments to be reviewed and renewed if, there are any changes in risk conditions, or the given budget is not enough to take necessary safety measures. Risk assessment should also be renewed within a certain period according to the legal regulations and legislations.

- With the help of FTOPSIS, the number of participant limit in the proposed risk management method became unlimited in order to increase the number of participant and accuracy of results.

- A risk index is added to this method with the help of FTOPSIS to guide safety experts in a more accurate and simple way. It was left to the users to interpret the resulting risk index whether it is in the acceptable level or not. Therefore, the proposed theory for finding risk index is specific for the project and is intended only as a guide for the determination of risk level to the user.

- The proposed method determines the optimal safety measures in accordance with a given budget according to the developed mixed-integer nonlinear programming model. Also, the method determines final OHS risk index and risk ranking according to determined optimal safety measures. There is no study in the literature about finding optimal safety measures with a specific budget.

- Due to the complex, dynamic and unique nature of the construction process, the proposed method was developed in a way based on qualitative risk assessment. The proposed method based on subjectivity due to the level of knowledge and experience of safety professionals rather than recorded historical data. Therefore, the proposed risk management method is universal based on real-life data and only gives project-specific results in which the risk assessment is carried out.

- With the help of the developed risk management method, contractors can easily perform risk management before the bidding phase and determine the optimum safety cost items according to their budgets. By this way, they can add to their proposals the possible budget they will spend on occupational health and safety. Nowadays, many contractors ignore this cost item during the tender phase and not take the necessary measures for occupational health and safety to ensure profitability during the construction phase. This inevitably leads to an increase in the number of occupational accidents. Therefore, if contractors determine an OHS budget by using this tool before the bidding phase, it is expected that there will be a significant decrease in the number of occupational accidents.

- A case study was conducted to see the usability of the proposed methodology and whether it reached the specified aims. According to this case study, the users mentioned that the method and the tool are functional, it provides ease of use in risk assessment process, and it is very important for the construction sector to provide optimal safety measures for a specified budget.

- With the help of developed MS Excel Tool and by following the proposed methodology, risk assessment can be performed by all users on any computer where Microsoft Office is installed.

Recommendations for future studies can be listed as follows:

- A case study was carried out on a project in progress. Therefore, since the amount spent for OHS at the end of the work is not clear, and the expenditures continue, the total budget spent for OHS and the results of the proposed tool could not be compared. For this reason, the accuracy of the judgments of the users and the results of the proposed tool can be evaluated and compared with the actual data by conducting case studies in projects with different percentages of completion.
- The proposed method is based on the safety risk management of building projects. However, it can be easily adapted to the whole construction sector and even to all other sectors.
- A general scale can be established for the risk mitigation rate of the selected cost items. By this way, this part of the proposed tool can be filled by more users, and the accuracy of the proposed tool can be increased.
- A general risk levelling scale can be established for determining risk level from risk index. This will enable risk acceptance levels to be determined in accordance with proposed risk scale. By this way, the evaluation left to the users' interpretation in determining the level of risk in this study can be made according to certain criteria for all users.

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