Effective Risk Assessment Models for Construction Industry

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ABSTRACT

The construction industry is known to have overwhelming numbers of occupational accidents worldwide, which attribute to continuous demand for care and improvement. Due to this enormous risk, identifying the contributing factors should be prioritized for accident prevention and hazard control. However, it is evident that the lack of enforcement and preventive inspection in Turkish Republic of North Cyprus causes the necessity of new approaches for improvement.

To begin with, we collected data from the Ministry of Labor to gather information on accident modes, work trades, and loss of working days due to occupational accidents. Subsequently, checklists were prepared based on the rules and regulations in North Cyprus construction industry.

There is no risk assessment model study in the literature related to North Cyprus construction industry. The main aim of the thesis is to develop an effective risk assessment models for North Cyprus construction industry to create a better working environment for employees by minimizing the risk at the site and taking the precautions. Various risk assessment models were identified to be modified, developed then applied in the North Cyprus construction industry: traditional, preliminary, fuzzy, and modified fuzzy risk assessment models. These models implemented in the North Cyprus construction industry to determine the most suitable and effective one.

Apart from the insufficiency in general site safety, this study shows that the safety barriers are not adequate, accident frequency and severity of accidents are high; especially for falling from a height.

Generally, worker characteristics were composed of disproportionally low experienced workers, and the training given was found to be inadequate. In addition, the risk level for each accident mode and the hazard index for different construction sites are calculated. All of these helped us develop a special Risk Assessment Model unique to North Cyprus circumstances.

Keywords: risk assessment models, hazard index, occupational accidents, accident prevention

ÖZ

Dünya genelinde en çok sayıda iş kazasının inşaat sektöründe olduğu bilinmektedir. Bunun sebebi ise, inşaat sektörünün doğasında var olan tehlikenin sürekli bakım ve iyileştirme gerektiren bir alan haline gelmesinden kaynaklanmaktadır. Risk yüksektir ve odak, kazayı önleme ve tehlike kontrolü için iyi bir yapıyı sürdürmeyi zorlaştıran faktörlerin belirlenmesi üzerinde olmalıdır. Ayrıca, Kuzey Kıbrıs Türk Cumhuriyetin'de yaptırım ve önleyici denetim eksikliğinin, iyileştirme için yeni yaklaşımların gerekliliğine neden olduğu görülmektedir.

Bu çalışmada, öncelikle Çalışma Bakanlığı'ndan veri topladık ve kaza şekilleri, iş tanımları ve iş günü kayıplarına göre verileri düzenledik. İkinci olarak, Kuzey Kıbrıs inşaat sektöründeki kural ve yönetmeliklere dayalı olarak bir kontrol listesi hazırlanmıştır.

Kuzey Kıbrıs’ta risk degerlendirme modelleri ile ilgili bir çalışma bulunmamatadır. Bu çalışmanın esas amacı Kuzey Kıbrıs inşaat endüstrisinde kullanılmak üzere bir risk değerlendirme modeli geliştirmek ve böylelikle çalışanlar için riski en aza indirip daha iyi bir çalıştırma ortamı yaratmaktır. Bu sebeble, Kuzey Kıbrıs inşaat endüstrisinde farklı risk değerlendirme modelleri düzenlenip geliştirilmiş ve ardından uygulanmışıtr. Bunlar, geleneksel, ön, bulanık ve değiştirilmiş bulanık risk değerlendirme modelleri die adlandırılmaktadır. Farklı modellerin inşaat sahalarında uygulanma amacı en uygun ve etkili modeli seçebilmek içindir.

Bu çalışma, genel saha güvenliğinin ve güvenlik bariyerlerinin yetersiz olduğunu, özellikle de yüksekten düşmelerin şiddetinin yüksek olduğunu ve sık sık kaza yapma olasılıkları bulunduğunu göstermektedir. Genel işçi özelliğine göre az sayıda deneyimli işçi olduğu ve işçilere verilen eğitim sayısının yeterli olmadığı belirlenmiştir. Her kaza tipi için risk seviyesi ve farklı inşaat durumları için tehlike indeksi hesaplanmıştır. Tüm bu çalışma, Kuzey Kıbrısta kullanılaibilecek örgün modeli geliştrimemize yardımcı olmaktadır.

Anahtar Kelimeler: risk değerlendirme modelleri, tehlike indeksi, iş kazaları, kaza önleme

DEDICATION

To my family

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A	Scaffolding and Ladder Usage
A1	Volume of Scaffolding and Ladder Usage
A2	Height of the Ladder/Scaffold to Be Used
A3	Adequacy of Design
AHP	Analytical Hierarchy Process
ANP	Analytic Network Process
AP	Accident Possibility
B	Construction Tools and Machinery Use
B1	Volume of Plant and Machinery Used
B2	Operating Platform of Plant and Machinery
B3	Site Layout
B4	Volume of Tools Used
B5	Type of Tools Used
C	Being Compressed by Equipment or Objects
C	Lifting and Hoisting Machinery
C1	Volume of Lifting and Hosting Involved
C2	Nature of Materials Lifted and Hoisted
C3	Operating Platform
C4	Nature of Site Vicinity
CE	Contact with Electricity
CFPR	Consistent Fuzzy Preference Relations
CI	Consistency Index
CM	Contact with Machinery and Moving Parts

COPRAS	Complex Proportional Assessment
D	Welding Cutting and Hot Works
D1	The Volume of Welding, Cutting and Hot Works
D2	Location of Welding
E	Excavation Works
E1	Excavation Configuration
E2	Geological Conditions
E3	Underground Utilities
E4	Nearby Vehicular Traffic
E5	Nearby Structures
F	Falls
F	Occurrence Frequency
F	Roof Works
F1	Volume of Roofing Involved
F2	Height of the Roof
F3	Roofing Material Property
F4	Inclination of the Roof
FH	Fall from Height
FPR	Fuzzy Preference Relation
FRAM	Fuzzy Risk Assessment Model
FV	Fall from Vehicle
G	Concrete Works
G1	Concrete Configuration (Volume, Location and Etc.)
G2	Concrete Mixing (In Situ Ready Mix and Etc.)
G3	Concrete/Material Transportation and Placing

G4	Curing Method
HI	Hazard Index
LWD	Lost Working Day
MPR	Multiplicative Preference Relation
NC	North Cyprus
OHS	Occupational Health and Safety
PPE	Personal Protective Equipment
RAM	Risk Assessment Model
RL	Risk Level
S	Severity
SB	Safety Barrier
SC	Safety Climate
SMV	Being Struck by Moving Vehicles
SVI	Severity Index
T	Time of the Activity
TA	Traffic Accident
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
TRNC	Turkish Republic of North Cyprus
W	Worker Characteristic

Chapter 1

INTRODUCTION

Providing a safer work environment for employees and employers is the most paramount issue in discussing and solving the problems at the site. The importance of occupational safety and health is to minimize the possibility of occupational accidents, to provide a better working environment to protect employees' health and to take precautions to reduce the occupational diseases that may occur at the site. Due to this reason, determining risks and hazards at the site is essential. All the preventive measures are taken to avoid the hazard and minimize the risk at the site. The information regarding occupational health and safety in the construction industry is given at the beginning of the introduction section. A detailed literature review is discussed in the following sections. The importance of occupational health and safety is highlighted, and the factors that reduce safety at the site are listed.

Furthermore, preventive measures used in the literature and the existing risk assessment models are discussed. In addition to that, the variables mainly used in risk assessment models are classified. Different methods to determine the safety at the site used in the previous studies are discussed. Various risk assessment models are compared, and the advantages and disadvantages of each are identified. Rules and regulations followed in the North Cyprus construction industry are listed, and at the end of the introduction section, the contribution and implication of this study are summarized.

1.1 Occupational Health and Safety in Construction Industry

Occupational Health and Safety (OHS) is a concept concerned with preventing accidents in the workplace, minimizing loss and providing a healthy and safe work environment for employees as well as the employers.

1.1.1 The Importance of Occupational Health and Safety

Unquestionably, OHS is vital for employees' health since they spend most of their time on the site (Topal, 2011). It also plays a unique role in construction industry due to its hazardous nature.

1.1.2 Factors Reducing Safety

The construction industry has the highest accident risks at the site as a consequence of its diversity in work trades (Holmes et al., 1999; Işık & Atasoylu, 2017; Laitinen & Päivärinta, 2010; Topal & Atasoylu, 2022). According to the detailed literature review, the most common reasons for accidents were found to the lack of enforcement (Boadu et al., 2021; Kartam et al., 2000); the limited usage of personal protective equipment (PPE), adequacy of training on how to work with machines and equipment, the experience of employers on the job assigned by the managers (Abukhashabah et al., 2020) and skilled workers availability (Boadu et al., 2020).

In addition, numerous employees are from foreign countries, making communication at the site difficult. Moreover, occasionally jobs are not distributed according to the skills of employees, especially for small-sized family-owned construction companies. In addition to these, construction workers are constantly moved from one construction site to another, which exposes them to different working conditions and risks. It is also observed that considerable proportion of construction workers are often asked to work outside of the regular working hours to complete the job on time. Therefore, the time of the activity can be considered as another critical factor that affects site safety.

All these factors contribute to the rise in the percentage of occupational accidents at construction sites, which is why we included them as variables in our study.

1.1.3 Preventative Suggestions

Applying OHS rules and regulations is the responsibility of employees, employers (Toole & Gambatese, 2008), and governments, which stresses the cruciality of cooperation. Therefore, site engineers' and experienced employers' perspectives are crucial to determine the precautions (Törner & Pousette, 2009).

Moreover, identifying the hazard index (HI) and applying risk assessment models (RAM) to determine the risk are the core safety practices for construction industry (Namian et al., 2018).

1.1.4 Risk Assessment Models

After the historical data is collected and risk causes are determined for each type of accident, RAMs can be developed by the current rules and regulations (Tanvi Newaz et al., 2022). There are qualitative and quantitative RAMs in the construction industry. A detailed discussion related to RAMs is given in the following sections.

1.1.4.1 Measures in Risk Assessment Models

Safety barrier is a practical way of quantifying the effectiveness of safety precautions and measures. The historical accident data can be used to summarize the type of accidents, injured body parts and lost working days (LWDs) for each type of accident, to define safety barriers at the site. These barriers were determined based on the job description and previously collected data related to the accident reports to understand the nature of the accident. Thus, the safety barrier is crucial when it comes to reducing occupational accidents at the site and it should be an essential part of any RAM.

On the other hand, the abundance and LWDs of individual accident types can be used to identify the severity of each accident which is another useful measure in risk assessment.

Thirdly, the safety climate can be determined by the general attitudes and perceptions of the site engineers and employees regarding safety in the working environment. This can differ from country to country, thus each country's specific rules and regulations should also be considered (Meliá et al., 2008) which might impact the methodology of each study. However the importance of safety climate is controversial as it has been found that there is a significant relationship between safety climate and safe work behavior (Fernández-Muñiz et al., 2009; Mohamed, 2002), but there is no relationship between safety climate and safety performance (Glendon & Litherland, 2001).

Furthermore, the HI can be defined as a preliminary RAM used to determine a vague risk level for different sites and rank them accordingly. This helps companies to allocate resources and time to sites in need to improve OHS.

1.2 Literature Review on Occupational Health and Safety

1.2.1 Impact of Compromised Safety in Workplace

According to the previous studies, apart from the risk of injuries, working in a hazardous, risky work environment also reduces the employers' performance as it induces stress. Moreover, occupational accidents affect the employee's psychological and family life (Karakhan & Gambatese, 2018).

1.2.2 Various Methods Used in Previous Studies

The modified safety climate questionnaire was used in the previous resources (Abukhashabah et al., 2020; Boadu et al., 2021; Buniya et al., 2021; Carter & Smith, 2006; Glendon & Litherland, 2001; Guldenmund, 2007; Jannadi & Bu-Khamsin, 2002; Kines et al., 2010; Xia et al., 2022) to check the structure of safety climate.

Another way of measuring safety at the workplace is the safety observation method, where the site visits are made without any notice to the selected sites, safety measures are observed and noted, and the results are distributed to them in a few days (Laitinen & Päivärinta, 2010). This method has been used since 1993 and the measures taken into account are the working conditions, usage of PPE, and the training provided on how to use machines and equipment. As a result, the appropriate measures are determined for the construction sites.

The modular integrated construction project is another widely used safety measurement method in construction sites where jobs are categorized by the type work it involves. Following which, safety index is calculated and suggestions on how to improve are made separately for each group (Leong & Shariff, 2008; Mohandes, Durdyev, et al., 2022).

Analytical Hierarchy Process (AHP) is a method used to determine the weight of each question in a questionnaire to increase the reliability of the study. Initially, the relevance of each question is determined and more weight (higher importance degree) is given to the ones that are more important using pairwise comparison matrices. (Bernasconi et al., 2010; H. X. Li et al., 2013; C. J. Lin et al., 2020; Özdağoğlu, 2007; Saaty, 2004; Zhang & Zou, 2007). Linguistic variables can be used to rate the risk factors at the site on the prepared or administrated checklists (Gou et al., 2021; Halperin & McCann, 2004; Pinto, 2014; Rezakhani, 2012). However, downside of AHP is that it requires longer implementation time and iterations, thus it is not preferred in large and complex projects. In these circumstances, Fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Analytic Network Process (ANP) can be also used to calculate the weights in different RAMs. It is a decision making problems to select the best option (Chi & Han, 2013; Karimiazari et al., 2011).

Moreover, Fuzzy linguistic words come into play when data cannot be described numerically. Fuzzy logic, which was developed in 1965 by Lotfy A. Zadeh, theory provided an alternative solution for different cases when data is not binary. The world's general view consists of hundreds of intervals, similarities, and contrasts between 0 and 1. Initially, the fuzzy sets, functions and rules are determined, following which defuzzification value is calculated as the outcome. (L. A. Zadeh, 1975; Lotfi A. Zadeh, 1965, 1978; Zimmermann, 2010).

1.2.3 Risk Assessment Models in the Literature

The qualitative risk assessment method (QRAM) was developed using four different measures: safety barriers, severity factors, safety climate, and accident possibilities (Pinto, 2014). Those measures are determined for each type of accident listed for the specific country. In order to apply the method, the construction sites are selected. Then, by using the checklist, current safety levels were identified. Similarly, for the possibility of accidents, questionnaires are prepared for each type of accident and then answered using linguistic terms. Finally, safety barriers are determined without a checklist because different situations may affect the decisions. Aggregated values for these measures are determined using the Fuzzy OR operator or Hammacher OR operator. The risk is determined by the fuzzy AND operator. However, they are some issues regarding the weight of the dimensions and severity and safety climate calculations (Pinto, 2014).

Risk assessment can be performed using the Monte Carlo method, which considers optimistic and pessimistic values to determine the risk at the site. Nowadays, the Monte Carlo method is used for environmental impact assessment, but it is not easy to apply (Larionov et al., 2021). The risk is calculated by multiplying probability and expected damage. The expression used to calculate the risk is revised for different scenarios the safety experts have to have reliable results. The Monte Carlo method helps to reduce the risk by selecting the optimized method. This method can be used where the initial data is given in probabilistic intervals (Larionov et al., 2021).

The multi attribute decision making method is also used in construction sites. The multi attribute decision making methods (Gou et al., 2021; Gul, 2018; Kuo & Lu, 2013; Tamošaitienė et al., 2013; Zavadskas et al., 2010) allows experts to assign the values on interval basis and the results can be changed by assign different weights to the factors. The weight of each factor calculated by using TOPSIS grey and Complex Proportional Assessment (COPRAS G). The best alternative can be selected by comparing the aggregated results obtained for the construction sites (Zavadskas et al., 2010). This study highlights the different risk level values by using different weight factors such as Fuzzy TOPSIS, and the COPRAS G. In addition, the risk level is different for each site since each has different site characteristics. Therefore, the decision-making process is essential in the RAM (Zavadskas et al., 2010).

According to Zeng et al. (2007), it is essential to determine the risk influencer and risk for different construction sites. Initially, risk magnitude is calculated using risk severity and risk likelihood. A new variable was added, called the factor index, to improve the efficiency and effectiveness of the model. The factor index is calculated using the checklist, and AHP determines the weights. Even if when the new variable was introduced, obtaining the risk magnitudes, risk likelihood, and contrasting with uncertainties is not easy in the construction industry, and expert opinions should revise the model (Zeng et al., 2007).

Delphi technique is used to collect information which is used by experts during the risk assessment. By the questionnaires through the different construction sites which is answered by different experts the site safety and risk can be determined. The reasons of accidents should be determined to improve the safety performance. At the end the qualitative RAM was developed based on the historical data to determine the risk levels for different work trades. The advantage of this model is that its considers the historical accident types and risk of each accident type is calculated and overall risk of each work trade can be calculated. The disadvantage of this method is the probability of accident can be calculated by using LWDs and on some construction site which is not always recorded. The model can be improved by considering different factors (Fung et al., 2012). In this model, the risk is calculated by multiplying the probability and severity.

A comprehensive hybrid fuzzy-based occupational risk assessment model is developed to identify, analyze, and evaluate the risk at the site. Risk identification is the first step of the model, followed by analysis and evaluations. The modified Delphi technique with a triangular fuzzy approach determines the risk factors, probability, and severity weights (Liu & Tsai, 2012; Mohandes & Zhang, 2019). However, this model is developed for only elevator maintenance workers at the site, and it should be reformulated to determine risk for another specific job. In addition, it only considers probability and severity variables, and new variables may increase the model's effectiveness (Mohandes & Zhang, 2019).

Construction safety index can be calculated for each site by multiplying the weight and rate for each attribute then the aggregated value is calculated for different sites (Ai Lin Teo & Yean Yng Ling, 2006; Mohandes, Abdelmageed, et al., 2022). The model has some disadvantages, such as checklists being designed for a specific country, so it should be redesigned by considering different countries' rules and regulations. The second disadvantage is that the number of experts who participate in this model is low (Ai Lin Teo & Yean Yng Ling, 2006).

The fuzzy RAM is used to rate the cost overrun risk. In the model designed by Dikmen et al. (2007) risk is identified using influence diagrams and for defined variable linguistic terms are selected. Expert opinions are highlighted using fuzzy rules to clarify the relationship between risk and risk factors. In the final step, the risk is determined using the fuzzy operation. The disadvantage of the model is that since the risk identifications and variables are defined according to the construction site, for different cases, the number of variables and risk influences might be different, which needs to improve the model accordingly (Dikmen et al., 2007).

Risk likelihood, accident severity, and current safety levels are used in the design of the RAM of Gurcanli & Mungen (2009) to deal with uncertainties that occurred by using the traditional method; instead, in this model, fuzzy rules are used. Since this model only focuses on daily activities, rather than the whole job, it might be the limitation of the model. Furthermore, this model does not include the financial focus on the construction site, which is another limitation. The checklist used in this model should be developed according to the country's rules and regulations, health and safety programs and their responsibilities, and the other decisions that affect the safety measures at the given construction sites (Gürcanli & Müngen, 2009). The point system used in the checklist has an advantage such that the site investigator or the civil engineer who performs the assessment can quickly evaluate them by linguistic terms. If it takes a lower overall value, they can increase the appropriate measures to increase the safety at the site (Gürcanli & Müngen, 2007).

Accident possibilities increase if the working environment is poorly designed and conditions are unsafe at the site. To reduce the risk at the site, the causes of accidents are divided hierarchically into different tasks (Carr & Tah, 2001; Tah & Carr, 2000) and by the workforce level. The prepared influence diagram and fuzzy concepts were used to determine the risk at the site. However, the disadvantages of the model are that using the historical data is not a straightforward approach in the RAM and the fuzzy approaches used in this system is not easy. For the complex project, it might not be easy (Y. H. Lin et al., 2011).

The accident types are classified according to the result of a permanent, revocable, or dead accident. The number of accidents for a given period and working conditions at the site should be identified. These are the sources of the given model, and the model has a disadvantage: predicting the risk exposure is not a straightforward task at the site. The working conditions are not constant, so the risk factors may change as well (Papazoglou et al., 2017). This model is appropriate when you have the expected frequency for specific work trade, such as scaffolds. Then safety barrier and their effectiveness are measured by site investigation. Safety barriers' effectiveness and the reduction of the probability of accidents are measured (Papazoglou et al., 2017).

In the model developed by Li et al. (2013), input parameters are modular construction processes. In order to apply the model, expert opinions are collected at the construction site, the precedence relationship, the cost, and the duration of each process are summarized, and project variation information is described. Risk is categorized as general, such as economic and political, in the plant, such as labor availability and skilled labor availability, and out site factors such as temperature and ventilation (H. X. Li et al., 2013).

1.2.4 Suggestions from Existing Literature

Including the cost in one of the variables in the model is essential because some companies have limited budgets for safety and training programs. However, it should be considered that reducing safety eventually increases the cost due to occupational accidents (Ariyanto et al., 2020). Cost-effective safety programs that assign safety precautions to the sites are used to develop a safer work environment based on the actual accident data and categorize the accidents according to the severity (Mohan & Zech, 2005).

According to the previous studies, safety can also enhance through a culture that appreciates employers' and employees' commitment and safety management system (Fernández-Muñiz et al., 2007). In order to achieve worker safety, program measures can be defined by the expert and implemented in the numerous stages of work at construction sites (Buniya et al., 2021).

In appendix A, the comparison table for RAM used in literature is presented. The thesis does not aim to criticize any existing methods available in the literature. The idea is to provide a comparison of existing methods' advantages and disadvantages, which will guide site engineers or safety professionals in deciding the appropriate model suitable for the country's conditions. Each method has some similarities and differences, which may increase the implementation time of the determination of the risk level, and the some of them requires extensive knowledge of Fuzzy Logic, simulation, and statistics which may affect the decision to choose the best method.

1.2.5 Current Situation in Northern Cyprus

There are rules and regulations already in place to reduce occupational accidents at the sites and minimize the loss. These are as follows:

- 08.08.1998: Workers’ health and safety legislation (22/1992 Act)
- 14.07.2008: Occupational Health and Safety Law
- 21.04.2009: Usage of PPE at workplace legislation

However, in the North Cyprus (NC) construction industry, there is no enforcement of these rules and regulations, making it challenging to control the safety at the site. Moreover, falling from a height is the most prevalent accident reported in NC construction industry, which is in accordance with what is observed around the globe (Abukhashabah et al., 2020; Tanvi Newaz et al., 2022). Furthermore, there is no RAM study in the literature related to NC construction industry.

1.3 Contribution and Implications of Our Study

Information above highlight the contrast between the OHS in NC compared to the worldwide standards, creating an urgency to act to close this gap. Our study aimed to do so, by developing an effective RAM to determine the risks at construction sites and take precautions. As discussed above, there are numerous RAMs in the literature which were all taken into account to determine the most applicable ones to NC. Then, these were modified and developed to further increase the reliability of the final risk assessment models. Following that, these models were implemented in NC construction sites to determine the most suitable and effective one. Uniqueness of our fuzzy RAM is that it has more variables compared to the existing models in the literature (summarized in Appendix A).

Chapter 2

RESEARCH METHODOLOGY

2.1 Traditional Risk Assessment Model

The traditional RAM developed by Fung et al. (Fung et al., 2010) was used to provide important information to site engineers, safety professionals, and government representatives to take essential precautions. It uses historical data available to implement the RAM. The model is modified by adding new indexes and updating the current model by considering the available data in the NC construction industry.

2.1.1 Historical Data Collection

Historical accident data was gathered from the NC Ministry of Labor and the Social Security Department of Labor by reviewing the 2008–2022 accident investigation reports. Work trades were identified, accident and injury types were categorized, and the LWD for each type of accident were calculated.

2.1.2 Determination of Accident Types

After reviewing the NC construction industry accident reports (2008–2022) from the labor office, eight different types of accidents were identified to be used in the study. These accident types are defined as falls (F), falls from heights (FH), falls from vehicles (FV), being struck by moving vehicles including heavy equipment (SMV), being compressed by equipment or objects (C), contact with machinery and moving parts (CM), traffic accidents (TA), and contact with electricity (CE).

2.1.3 Determination of Work Trades

Moreover, the 27 work trades were also identified from the data collected. The work trades are categorized as construction workers, aluminum workers, concreters, painters, ironworkers, excavator operators, electricians, tile tillers, regular employers, insulating workers, pattern makers, welders, digger operators, machine maintenance specialists, marble cutters, carpenters, tire repairman, ceramic layer, plasters, plumber, repairman, quarryman, foreman, builder, driver, security guard. Each work trade has special machinery and equipment (Jeelani et al., 2016) , thus it's necessary to implement various precautions. Some workers work on construction sites where they do not have any specific job defined by the managers.

2.1.4 Determination of Safety Barrier Index

Several meetings were conducted with civil engineers working on the construction sites to list the job descriptions. This site investigation defines accident types for each work trade (Sanni-Anibire et al., 2020). Implementing the appropriate preventive measures is essential in reducing the risks at the site. It aids in analyzing work tasks, site hazards, and injured body parts. From the accident investigation reports, the number of accidents and the affected body part is summarized and used to assign the safety barriers accordingly. Table 1 summarizes the estimated safety barriers for each work task. Some accident modes are removed from the analysis because of insufficient data related to further studies, these accident types (*) are shown in the table below.

Table 1: Estimation of effectiveness of safety barriers.

Accident Modes	**Injured Body Part (Number of Accident), Preventive Measure, Work Trade**		
Falls	Leg/Foot/Toe (4) Hand/Finger (7)	Fixed Standard Railings Good house keeping Cover the holes Boot	1. Excavation 2. Construction of walls foundation 3. Cement pouring into molds

	Trunk/Back (2)	Hard Hat	4. Removal 5. Scaffolding
Falling from height	Shoulder/Arm (10) Head/Face/Neck (1) Leg/Foot/Toe (35) Hand/Finger (28) Trunk/Back (6) Spinal Cord (1) Cranium (2) Waist (3) Other (10) Multiple (1)	Harness Guard Rail Safety Net Proper scaffolding	1. Excavation 2. Construction of walls foundation 3. Cement pouring into molds 4. Removal 5. Scaffolding
Falling from vehicle	Head/Face/Neck (1) Leg/Foot/Toe (3) Trunk/Back (1) Waist (1)	Safety Belts Training Operating Instructions	1. Excavation 2. Construction of walls foundation
Struck by moving vehicles	Leg/Foot/Toe (12) Hand/Finger (12) Trunk/Back (3) Spinal Cord (2) Waist (1) Other (3)	Hard Hat Goggles Special Gloves Operating Instructions Separating work areas Barriers	1. Excavation 2. Construction of walls foundation
Compressed by moving objects	Head/Face/Neck (1) Leg/Foot/Toe (3) Hand/Finger (15) Other (2)	Special Gloves Hard Hat Safety Boots (toe guard) Operating Instructions	1. Excavation 2. Construction of walls foundation
Contact with machinery	Head/Face/Neck (6) Leg/Foot/Toe (5)	Special Gloves Hard Hat Personal Protective Equipment Machinery guards	1. Cement pouring into molds 2. Cut steel rebar

	Hand/Finger (24) Trunk/Back (1) Other (4)		
Lost Bouncy*	Head/Face/Neck (1)		
Amputations *	Head/Face/Neck (2)	Special Gloves Hard Hat	1. Cut steel rebar 2. Remove the mold of concrete beam.
Head trauma*	Head/Face/Neck (1)	Special Gloves Hard Hat	
Traffic Accident	Shoulder/Arm (2) Head/Face/Neck (1) Trunk/Back (1) Other (4)		
Contact with electricity	Other (4)	Non-Conducting Boot Safety Working Procedure Proper maintenance Lock out and tag out Gloves	

2.1.5 Determination of Severity Index

The severity index (SVI) is used in traditional RAM in numerous ways and is based on the LWDs obtained from historical data. The SVI for traditional RAM can be calculated through the equation 1 to 3.

SVI1= LWD in each trade/average LWD (1)

SVI2= LWD in each accident type/average LWD (2)

SVI3= safety barrier value in each mode/average safety barrier value) (3)

2.1.6 Determination of Risk by Traditional Risk Assessment Model

The risk level determination in the traditional RAM method is computed by the use of the probability and severity parameters (Ak, 2020; Fung et al., 2010). The risk can be calculated through equations 4, 5, and 6.

$$\text{Risk} = (F1) \cdot (SVI1) \quad (4)$$

Where F1 (Accident occurrence frequency for each trade) = Number of accidents in each trade/total number of accidents,

$$\text{Risk} = (F2) \cdot (SVI2) \quad (5)$$

Where F2 (Frequency of accidents for each mode) = Number of accidents in each mode/total number of accidents

$$\text{Risk} = (F3) \cdot (SVI2+SVI3) \quad (6)$$

Where F3 (Accident occurrence frequency for each mode) = Number of accidents in each mode/total number of accidents

2.2 Preliminary Risk Assessment Model

The preliminary RAM developed by Patel et al. (Patel & Jha, 2016) was modified considering the rules, regulations and accident investigation reports for the NC construction industry . This model is used to evaluate the hazard levels of different construction projects and compare the hazard index of various hazardous trades. HI calculation is a preliminary step of the Fuzzy Risk Assessment Model (FRAM) and is one of the straightforward techniques used in RAMs (Ak, 2020) since it has less implementation time. Moreover, it is practical as the companies have numerous construction sites and need a preliminary RAM to determine which sites should be prioritized. Small-sized construction sites are selected in the NC construction industry to implement this model.

2.2.1 Determination of Work Trades and Their Attributes

Seven work trades are analyzed (which were determined through NC accident investigation records) to determine each construction site's risk level and overall hazard level. These work trades are rearranged using the model developed by Patel et al. (2016). As presented in table 2, their modified attributes are determined using the historical data and reviewing the rules and regulations applied in the NC construction industry. That is the preliminary requirement of hazard index calculations for construction sites.

Table 2: Work trades and their attributes.

A. Scaffolding and ladder usage	A1 Volume of scaffolding and ladder usage
	A2 Height of the scaffold/ladder to be used
	A3 Adequacy of design
B. Construction tools and machinery use	B1 Volume of plant and machinery used
	B2 Operating platform of plant and machinery
	B3 Site layout
	B4 Volume of tools used
	B5 Type of tools used
C. Lifting and hoisting machinery	C1 Volume of lifting and hosting involved
	C2 Nature of materials lifted and hoisted
	C3 Operating platform
	C4 Nature of site vicinity
D. Welding cutting and hot works	D1 The volume of welding, cutting and hot works
	D2 Location of welding
E. Excavation Works	E1 Excavation configuration
	E2 Geological conditions
	E3 Underground utilities
	E4 Nearby vehicular traffic
	E5 Nearby structures
F. Roof Works	F1 Volume of roofing involved
	F2 Height of the roof
	F3 Roofing material property
	F4 Inclination of the roof
G. Concrete Works	G1 Concrete configuration (volume, location and etc.)
	G2 Concrete mixing (in situ ready mix and etc.)
	G3 Concrete/material transportation and placing
	G4 Curing method

2.2.2 Preparing the Pairwise Comparison Matrices

A pairwise comparison matrix was prepared by considering the work trades and their attributes. An expert evaluation of the pairwise comparisons of work trade hazards was completed by conducting face-to-face interview with the civil engineers responsible for the projects. To complete the pairwise comparison matrix, each civil engineer used fuzzy numbers to rate relative importance among seven hazardous trades and their attributes defined in table 2. Fuzzy number 1 stands for equal importance, 3 stands for weak importance, 5 stands for moderate importance, 7 stands for strong importance, 9 stands for absolute importance, and 2,4,6,8 are intermediate values. The consistent fuzzy preference relations method determines the relative weights of 7 hazardous trades and their 34 attributes by MS-Excel.

2.2.3 Determination of Participating Expert

The construction site is evaluated by applying the different checklists prepared in this study to analyze the situation related to the effectiveness of safety barriers, determination of accident possibility factors, and current safety level. For each site, the site engineers responsible for the project are asked to complete the checklist and provide guidance to communicate with the construction workers whenever necessary. In this case, several meetings were held with civil engineers working on the construction companies. Eleven civil engineers working at those construction sites were selected randomly in this study to complete prepared pairwise comparison matrices (4 for the first site, 4 for the second site, and 3 for the third site). Civil engineers' experiences in this work ranged between 4 and 20 years. Their job description covered site investigations, supervision, safety at work, project planning, and scheduling material and equipment purchases and deliveries. Furthermore, they are responsible for problem-solving approaches at the site, preparing the site reports, and considering the legal and public requirements for project completion.

Pairwise comparison matrices are used in this study to determine the weights (Sanni-Anibire et al., 2020) assigned to the part of the current safety level checklist and for preliminary RAM. Moreover, these were used to determine the required steps for AHP.

2.2.4 The Use of Analytical Hierarchy Process

The AHP assigns the importance of each part in the checklist for determining the necessary measures. Secondly, the AHP defines the weight of the variables on the hazard index calculations. The steps required to determine the importance degree (weight) are given in the following sections.

2.2.5 Engineers Rated the Relative Importance of Hazardous Work Trades and Their Attributes

The site engineers are appointed for the work trade comparisons. Then, the site engineers are assigned a level of importance ranging from one to nine to work trade. The pairwise comparison matrix is then effectively performed by the site engineers. The sample of the pairwise comparison matrix is shown in table 3.

Table 3: Example of pairwise comparison matrix for hazardous work trades* identified by the civil engineers.

Job Title							
Experience							
Project Size							
Location of the Project							
	A	B	C	D	E	F	G
A	1						
B		1					

C			1				
D				1			
E					1		
F						1	
G							1

*Work trades and attributes are listed in Table 2

2.2.6 Aggregating the Input Data and Forming the Initial Matrix by Geometric Mean

A pairwise comparison matrix conducted by civil engineers are collected and summarized from the site visits and face-to-face interviews. The next step is to use equation seven to get aggregated input data for forming an initial matrix by a geometric mean.

$$\mathrm{r_{ij}} = \left(\mathrm{r_{ij}^{1} X r_{ij}^{2} X \dots r_{ij}^{m}}\right)^{\frac{1}{m}} \mathrm{i, j} \in (1,2,\dots,\mathrm{n}) \text{ in which m= number of experts} \quad (7)$$

r_{ij}^{m}= hazard level of the risk determined by the mth respondents

2.2.7 Converting Initial Matrix from MPR to FPR

Responses by the experts are in multiplicative preference relations (MPR) matrix, rij, as shown in table 11. The initial matrix is converted from MPR to Fuzzy preference relations (FPR) matrix by using equations 8 and 9.

$$\mathrm{Y_{ij}} = \frac{(1+\log_9 \mathrm{r_{ij}})}{2} \quad (8)$$

$$\mathrm{Y_{ij}} + \mathrm{Y_{ji}} = 1 \quad (9)$$

Y_{ij}^{m}= fuzzy relations matrix indices for mth respondents

2.2.8 Obtaining Complete Consistent Fuzzy Preference Relation Matrix

After obtaining the FPR matrix, a consistent FPR matrix using equations 10 and 11 was developed.

$$r'_{ij} = 9^{(2XY_{ij}-1)} \tag{10}$$

$$R' = \left[r'_{ij}\right] \tag{11}$$

r'_{ij} = consistent fuzzy relations matrix indices for mth respondents

2.2.9 Determining the Relative Importance of Hazardous Trades

Determining the Consistent Fuzzy Relations Matrix (CFRM) allows the site engineers to assess the relative importance of hazardous trades to highlight the need for risk assessment and risk determination for the site. Hazard level determination will enable engineers to take precautions to minimize the risks at the site. To determine the relative importance of hazardous trades first $\lambda_{\max}$ is determined through the equation 12.

$$R'.H = \lambda_{\max}\ .\mathrm{H} \tag{12}$$

2.2.10 The BNP Represents the Risk Impact (I) of the Attributes

The risk impact of each attribute is determined using equations 13 to 16. The risk impact of the attributes is essential to calculate since it is used to determine the hazard index.

BNP=(UF+MF-2XLF)/3+LF where (13)

LF: average of lower value of the fuzzy triangular numbers, MF: average of middle value of the fuzzy triangular numbers, UF: average of upper value of the fuzzy triangular numbers the input parameters definition and triangular fuzzy numbers summarized on table 4 (Patel et al., 2016).

$$LF = (\sum_{i=1}^{m} LF_i).\left(\frac{1}{m}\right) \quad (14)$$

$$MF = (\sum_{i=1}^{m} MF_i).\left(\frac{1}{m}\right) \quad (15)$$

$$UF = (\sum_{i=1}^{m} UF_i).\left(\frac{1}{m}\right) \quad (16)$$

Table 4: Input parameter and triangular fuzzy numbers (TFNs)

Input Parameter	Definition	TFN (L, M, U)
1	No impact	(0.0, 0.0, 0.1)
2	Slight impact	(0.0, 0.1, 0.3)
3	Mild impact	(0.1, 0.3, 0.5)
4	Moderate impact	(0.3, 0.5, 0.7)
5	High impact	(0.5, 0.7, 0.9)
6	Very high impact	(0.7, 0.9, 1.0)
7	Severe impact	(0.9, 1.0, 1.0)

2.2.11 Determination of Overall Hazard Level

The overall hazard level can be determined by calculating the relative importance of hazardous trade and HI values. The relative importance of hazardous trades is calculated by using equation 17.

W=L . H   where (17)

Where L is local relative importance and H is relative importance of hazardous trade.

The HI of attributes and Overall Hazard Level is calculated by equation 18 and 19.

HI=W . I (18)

$$Overall\ Hazard\ Level = \frac{[(\sum HI) - 0.033]}{0.9} \quad (19)$$

Furthermore, the Kruskal Wallis test determines if there is a meaningful difference between the mean of each hazard index of hazardous trades at the construction sites.

2.3 Fuzzy Risk Assessment Model

Different approaches were used to calculate the variables compared to the QRAM in the FRAM. FRAM is designed for the NC construction industry and the other countries that share similar working environment characteristics and it aims to determine the risk at the construction site in a straightforward manner. The QRAM developed by Pinto (2014) is modified considering the NC rules and regulations and the available data collected from the NC construction industry. The variables used in the model can be summarized as current safety level, safety barrier, accident possibility, and severity.

2.3.1 Determination of Current Safety Level

The checklists were prepared to determine the current safety level at construction sites and are presented in Appendix B. Questions were prepared based on NC OHS rules and regulations to determine the current safety level (Lestari et al., 2020; Topal, 2011). In order to determine the weight of each part of the checklist, the AHP was used (Ai Lin Teo & Yean Yng Ling, 2006).

2.3.2 Determination of Safety Barrier

The safety barrier value is calculated using the table presented in Appendix C. In each site visit, proportion of safety barrier preventive measures in place is checked by site engineers, and aggregated values are calculated. Presence of preventive measures reduce risk, whereas the absence increases the risk.

Safety barriers (Papazoglou et al., 2017; Patel et al., 2016; Pinto, 2014; Solomon & Esmaeili, 2021; Topal & Atasoylu, 2022) highlight the necessity of protective equipment, which improves the current system on the construction site.

2.3.3 Determination of Accident Possibility

The accident types were used in section 2.1.2 to modify the previously published checklist (Pinto, 2014) to determine the possibility of each accident mode at NC construction sites. For each type of accident, different set of questions was used to collect the data in the site visits. The modified checklist is presented in Appendix D.

2.3.4 Determination of Severity

Accident severity is determined for each construction site by using equation 20. In order to obtain the severity, the revised equation on the model developed by Fung et al. (2010) is used. Fung et al. (2010) used three indicators: person-days lost, fracture, and amputation. In this study, number of accidents and LWDs are used as indicators to get the severity of each type of accidents (Fung et al., 2010).

$$\text{Severity} = F \cdot S \tag{20}$$

Where F is the number of accidents in each mode/total number of accidents and S ıs LWD in each mode/average LWD.

FRAM uses historical values to determine the severity (Fung et al., 2012; Gürcanli & Müngen, 2009; Liu & Tsai, 2012; Pinto, 2014; Topal & Atasoylu, 2022; Zeng et al., 2007) of accidents at the site.

2.3.5 Determination of Risk by Fuzzy Risk Assessment Model

The construction site's risk level is determined using historical data, site investigations, and expert opinions. The risk level obtained from this investigation shows the minimum risks at the site. In order to estimate the risk level of each accident type, equation (21) is used. The precautions for each accident type are determined after the estimated risk levels are calculated. The modified risk assessment model was developed by Pinto (2014) by using four variables (Pinto, 2014).

$$\text{Risk }(x)=Q\text{and}(SC,S_i(x),AP_i(x),SB_i(x)) \tag{21}$$

Where

SC: safety climate, AP: possibility factor, SB: safety barriers, S: severity

These represent the adequacy of the safety level in the construction site (SC), the possibility of each accident mode in the construction site (AP), the safety barrier of the construction site (SB), and the severity of each type of accident mode (S). The Fuzzy AND operator estimates the minimum risk level for each accident mode, as shown in equation 21. The Fuzzy risk assessment model (FRAM) established in the published work (Topal & Atasoylu, 2022) brings simplicity in application compared to QRAM. The newly developed model of FRAM is a practical approach that is applied easily in the NC construction industry and elsewhere to evaluate the risky conditions of construction sites. Applying FRAM to any construction site can help safety inspectors, site engineers, and managers take precautions and improve the safety and health of the workers at the site. Outstanding safety management was reached at the site by applying the appropriate RAMs and continuous improvements.

2.3.6 Determination of Risk by MATLAB

Safety barriers, severity, current safety level, accident possibility, and the risk level have five linguistic terms, and their combinations connected with and (intersection) lead to a total of 625 rules. Expert experience and engineering judgment played a virtual role in determining ‘if then’ rules (Dikmen et al., 2007; Zeng et al., 2007). The fuzzy function of the MATLAB program is used, 625 fuzzy rules are defined by linguistic words, triangular membership functions (Tah & Carr, 2000) are created, and defuzzification values are determined using the centroid method (Gul & Ak, 2018; Zeng et al., 2007). Five different linguistic terms are defined for each variable so that the expert can change the value assigned to each variable, and the outcome will differ. As a result of this number of possibilities, a significant number of fuzzy rules are defined in the system. Some of the mapping inputs are shown below.

Rule 1: If SC is very low and S is low and AP is low and SB is low then RL is very low

Rule 2: If SC is low and S is low and AP is low and SB is low then RL is low

Rule 3: If SC is average and S is low and AP is low and SB is low then RL is low

Rule 4: If SC is high and S is low and AP is low and SB is low then RL is low

In order to get final RL value min(mSC(x_1), mS(x_2), mAP(x_3), mSB(x_4)) expression is used.

The MATLAB program is used in this study, where there is no chance to evaluate the situation at the site by using crisp values. The limitation here is the skills required to use the MATLAB program at the site. After the fuzzy rules are created for different construction sites, risk levels are determined using this approach, and the results obtained from the formulas and MATLAB program are compared. In this way, the reliability of the outcome is checked.

2.4 Modified Fuzzy Risk Assessment Model

Modified FRAM consists of more variables compared to the FRAM developed by Topal and Atasoylu, 2022. Modified FRAM can be used to assess risk at different stages of construction works and for tasks performed on the construction site. On any given day, the site engineer, safety manager, or any employee responsible for site safety with an OHS background can use the checklist provided for each variable by assigning linguistic terms to calculate aggregated values. After that minimum of those variables would be selected to show the minimum risk level at the construction sites. In addition, an excel spreadsheet and MATLAB program can be used to assign linguistic terms to define the working conditions for a specific construction site and run the program to get the finalized risk level values. Linguistic terms can finally interpret the risk levels. After the risk level is determined, each site can take preventive measures. This model has an advantage over other methods since the risk levels are calculated differently, and it helps site engineers take quick decision-making approaches according to the results. If the newly added variables which is worker characteristics value is high, the risk would be low. Similarly, if the assigned jobs are completed during the regular working hours, the risk will be low; on the other hand, if the jobs are done during the night shifts or over time, the risk will be higher. For this purpose, the aggregated values for these two variables are calculated using the data obtained from the site visits.

2.4.1 The Necessity of Modified FRAM

The main reason why the new variables are introduced relative to the FRAM is that:

1) Having greater number of variables makes the model more effective and reliable. It is the first time in the literature that six variables are used in the RAM.

2) With the model developed by Topal and Atasoylu (2022), a prepared excel spreadsheet can be easily used by site engineers or safety managers so we can reach more people and increase the practical usage of the model.

3) According to the results presented by Fung et al. (2012), the number of training or the frequent training has significant impact on risk level determination. The modified FRAM will consider the training employers get during their working experience, which will affect the risk level determined at the site.

4) According to the results obtained by Albert and Hallowell (2012), the work experience affects the risk level determined at the site, so it is essential to measure this variable in the risk assessment model as well.

5) Modified FRAM consists of 2 more variables: worker characteristics (Saaty, 2004; Solomon & Esmaeili, 2021; Trillo-Cabello et al., 2021) and the time of the activity.

2.4.2 Measures of Worker Characteristics

Worker characteristics can be obtained by using table 5, as shown below. This table helps to measure and understand employer characteristics. The checklist below is filled out for each employee using direct questionnaire. If the workers are experienced, the value of 0 was assigned. If the employer is not experienced, then the value of 1 was assigned. This is because inexperienced workers are expected to have more accidents than the experienced workers. Finally, the weighted score will be calculated and reflected in the model. The worker characteristic was initially calculated through table 5, which also considers the usage of PPE. However, after the first site visits, it is believed that all the information except the PPE is related to the employer's own experienced and training; on the other hand, PPE can only be recorded during the site visits, which shows variation from time to time. Therefore, the worker characteristics measure is recalculated by removing the PPEs.

Table 5: Checklist for worker characteristic

Characteristics	YES	NO
Experience (more than 3 years of experience) of workers		
Training one time		
Training frequently		
Using PPE		

2.4.3 Measure of Time of the Activity

It should be considered that circadian rhythms impact workers' physiological responses which can increase the risk of occupational accidents. Thus this risk can potentially increase if companies try different shifts at the site and have long working hours to meet the customer demand. Therefore, site engineers will assign a value for the time of the day, which would be subjective.

2.4.4 Determination of Risk by Modified Fuzzy Risk Assessment Model

The risk level determination of modified FRAM can be done through the equation 22.

$$\text{Risk}(x)=Qand(SC, S_i(x), AP_i(x), SB_i(x), W(x), T(x)) \tag{22}$$

Where

SC: safety climate, AP: possibility factor, SB: safety barriers, S: severity, W: worker characteristic, T: time of the activity

Chapter 3

DATA ANALYSIS

3.1 Identification of the Types of Accident and Injuries in North Cyprus Construction Industry

The accident investigation reports analysis summarizes accident types and the number of LWDs. Organized data were then ranked according to the LWDs. After that, it is grouped to assign the severity level, which is minor, moderate, serious, severe, critical, and fatal (Buniya et al., 2021) of accidents at construction sites. The categorization is as follows:

Minor: LWD < 30 days
Moderate: 31–60 LWD
Serious: 61–90 LWD
Severe: 91–120 LWD
Critical: >120 LWD
Fatal: death—either immediately or after several LWD

There are 226 accidents case which is investigated in this study. According to the results, the FH was the most common accident in the NC construction industry between 2008 and 2022. The investigated accident years and the number of nonfatal and fatal injuries occurred in the construction industry are given in the figure 1 and 2 respectively.

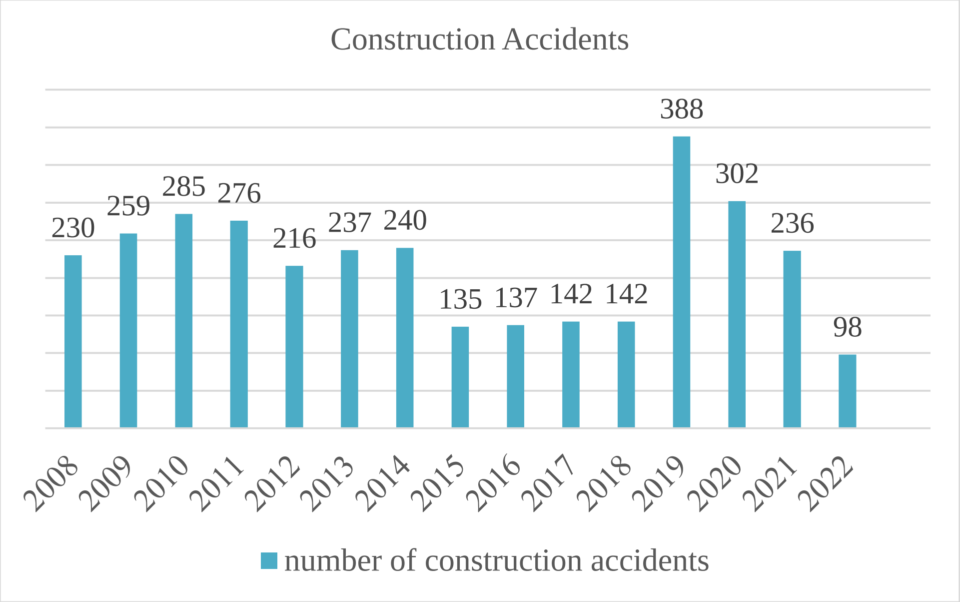

Figure 1: Number of accident reported between 2008 to 2022

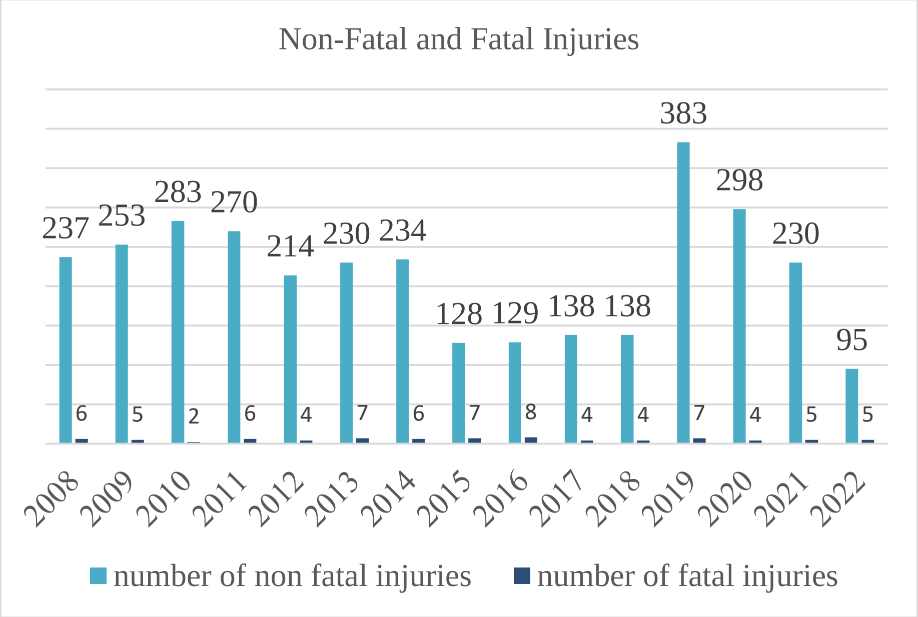

Figure 2: Number of non-fatal and fatal injuries

According to the statistics, the percentage of fatal injuries is changing from 1% to 6%. For small-sized industries, this ratio is high. The following figure presents the number of accidents according to the investigated years.

The number of accidents, frequency of occurrence (%), and severity level of each type of accident are shown in table 6. The moderate level is the most common severe type of accident, with 36.3% of total casualties. The number of each accident that falls in each severity rank is summarized in table 7. The average LWD was approximately 41 days between the analyzed years.

Table 6: Severity level of the accidents.

Severity Level	**Number of Accident**	**%**
Minor	57	25.2
Moderate	82	36.3
Serious	37	16.4
Severe	28	12.4
Critical	15	6.6
Fatal	7	3.1
Total	226	100

Table 7: Type of accidents and their % severity levels NC between 2008 and 2013.

	Percentage of Accidents within Severity Level					
Type of Accident (%)	**Minor**	**Moderate**	**Serious**	**Severe**	**Critical**	**Fatal**
Fall (6.6)	8.77	7.32	2.70	3.57	13.33	0.00
Falling from height (43.0)	29.82	37.80	62.16	57.14	40.00	57.14
Falling from vehicle (2.7)	3.51	3.66	0.00	3.57	0.00	0.00
Struck by moving vehicle including heavy equipment (16.0)	10.53	20.73	8.11	21.43	13.33	14.29
Compress by equipment or objects (9.3)	12.28	12.20	8.11	3.57	0.00	0.00

Contact with machinery and moving parts (18.0)	35.09	13.41	18.92	3.57	6.67	0.00
Traffic accidents (3.5)	0.00	4.88	0.00	7.14	13.33	0.00
Contact with electricity (1.8)	0.00	0.00	0.00	0.00	13.33	28.57
Total	100.00	100.00	100.00	100.00	100.00	100.00

The employers are classified according to their years of experience in the construction industry, as presented in table 8. More than three years of experience were classified as experienced. The type and location of injuries are shown in Tables 9 and 10, respectively.

Table 8: Percentage of accidents of experienced and new workers.

	Percentage of Accidents within Severity Level					
Experience (%)	**Minor**	**Moderate**	**Serious**	**Severe**	**Critical**	**Fatal**
Experienced (45.0)	42.11	46.34	54.05	42.86	46.67	14.29
Inexperienced (55.0)	57.89	53.66	45.95	57.14	53.33	85.71
Total	100.00	100.00	100.00	100.00	100.00	100.00

Table 9: Type of injuries within severity level.

	Percentage of Accidents within Severity Level					
Types of Injury (%)	**Minor**	**Moderate**	**Serious**	**Severe**	**Critical**	**Fatal**
Fracture (50.0)	22.81	59.76	62.16	82.14	33.33	0.00
Bruise (20.8)	33.33	19.51	18.92	10.71	13.33	0.00
Cut (14.2)	33.33	10.98	8.11	3.57	0.00	0.00
Chemical Burn (2.2)	5.26	2.44	0.00	0.00	0.00	0.00

Concussion (1.3)	1.75	0.00	0.00	0.00	6.67	14.29
Fatal (2.2)	0.00	0.00	0.00	0.00	0.00	71.43
Unknown (9.3)	3.51	7.32	10.81	3.57	46.67	14.29
Total	100	100	100	100	100	100

Table 10: Type of injured body location within severity level.

	Percentage of Accidents within Severity Level					
Injured Bodily Location (%)	**Minor**	**Moderate**	**Serious**	**Severe**	**Critical**	**Fatal**
Shoulder/Arm (5.3)	1.75	8.54	10.81	0.00	0.00	0.00
Head/Face/Neck (6.2)	10.53	6.10	2.70	0.00	13.33	0.00
Leg/Foot/Toe (27.4)	29.82	24.39	21.62	53.57	13.33	0.00
Hand/Finger (38.1)	45.61	48.78	40.54	17.86	0.00	0.00
Trunk/Back (6.2)	1.75	4.88	5.41	14.29	13.33	14.29
Spinal Cord (1.3)	5.26	0.00	0.00	0.00	0.00	0.00
Cranium (0.9)	0.00	0.00	2.70	0.00	6.67	0.00
Waist (2.2)	1.75	0.00	5.41	3.57	6.67	0.00
Other (11.9)	3.51	7.32	10.81	7.14	46.67	85.71
Multiple(Hand/Leg) (0.4)	0.00	0.00	0.00	3.57	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00

3.2 Determination of the Measures of Preliminary Risk Assessment Model

The civil engineers effectively perform the pairwise comparison matrix at different construction sites. Form the pairwise comparison matrix; the next step is to convert MPR to FPR, as shown table 11 and 12, respectively.

Table 11: MPR

	A1	A2	A3
A1	1,00	4,21	4,79
A2		1,00	3,20
A3			1,00

Table 12: FPR

	A1	A2	A3
A1	0,5000	0,8270	0,8560
A2	0,1730	0,5000	0,7650
A3	0,1440	0,2635	0,5000

After obtaining the FPR matrix next step is to develop a CFRM, as shown in Table 13.

Table 13: CFRM

	A1	A2	A3
A1	1,000	4,208	4,780
A2	0,238	1,000	3,204
A3	0,209	0,312	1,000

Furthermore, using the excel spreadsheet, several iterations are made, and $\lambda_{\max}$ is determined and resulted as $\lambda_{\max} = 0{,}674$ for A1, representing the volume of scaffolding and ladder usage.

3.3 Preparation of Checklist

The safety precautions are determined according to the NC OHS rules and regulations. The checklist for SC factors presented in Appendix B is measured at the site by checking four parts related to warning signs and instructions; loading, incorrect handling, related measures; ergonomic and physical hazards; and environmental factors. Yes or No questions were developed to determine the availability of warning signs and instructions and to check the environmental factors. For other parts 5-point, Likert scale (Ai Lin Teo & Yean Yng Ling, 2006) is used to measure the risk factors at the construction site. The aggregation operator was chosen by considering the most satisfactory qualities for risk assessment models. First empirical fitness is checked where the value of 1 corresponds to a very high-risk situation, and 0 corresponds to an absence of risk. Secondly, adaptability is checked where the aggregation of the membership degrees of different factors generates a synergy effect, such as a high accident possibility, indicating a high-risk situation at the site. Moreover, finally, semantic clarity is used to check and discriminate the factors which contribute the most negativity to estimate risk level. The AHP determined the critical weight of each part in the safety climate checklist. In the first step, the vector of criteria weights is computed and presented in table 14. Next, the option scores matrix is computed, and the third step requires ranking expert opinions. After three iterations by the MS-Excel program, the weights for each part were obtained (0.04, 0.62, 0.24, and 0.10, respectively). These weights are the eigenvector of relative importance. There are different numbers of questions in each part, and they are weighted equally. After the data were collected from the four construction sites, the weighted scores of each part were calculated. In this study, the consistency index (CI) is 0.185. After the eigenvectors are determined, λ max is calculated, and the consistency index is calculated. A perfectly consistent decision maker should always obtain CI = 0, but small inconsistency values may be tolerated (Eskander, 2018; Saaty, 2004).

Table 14: Pairwise comparison matrix for evaluating SC checklist weights.

	A	**B**	**C**	**D**
A	1.00	0.14	0.20	0.20
B	7.00	1.00	5.00	7.00
C	5.00	0.20	1.00	5.00
D	5.00	0.14	0.20	1.00

The second checklist, presented in Appendix D, is administrated to determine AP by Boolean (yes or no) type questions. In this study, a "Yes" answer represented no problem with the measures and therefore is assigned a weight of 0. Whereas a "No" answer signified a problem in the construction site evaluated and assigned a weighted score of 1. After the data were collected from the construction sites, weighted scores and AP were calculated.

3.4 Site Operations

Site operations are summarized below to determine the protective measures for each work task, which will be used to check the effectiveness of SB at the site. Site operations are listed by considering the routine work determined by experts. These operations can vary from site to site. The list below determines the appropriate SB in the construction industry for this study.

1. Excavation is carried out for the construction of wall foundations.
2. After excavation, lay out the foundation and backfill the remaining excavated area around the foundation with soil.
3. Check the levels of the foundation before concrete work.

4. A layer of damp-proof course material is laid down at floor level to protect walls from moisture.
5. Masonry work is carried out with cement mortar.
6. Masonry work of building is carried out in one go till the roof.
7. The roof slab of the building is poured after completing the masonry works.
8. Formwork is removed after slab pouring. Then plaster work begins. Generally, the internal walls of buildings are covered with a plastered layer, and external walls with pointing.
9. For doors and windows, frames are fixed in walls during masonry works. Panels are then fixed with hinges after plasterwork.
10. Different services are provided during construction, such as electricity, gas, water, and sanitary. Conducts for electricity supply are fixed in walls before plastering. Similarly, water supply and sanitary lines are also laid before pouring of building floor. It should be noted that gas lines are not fixed in walls or slabs. The gas line remains open in the air.

After the job descriptions were listed, appropriate safety measures and PPE were listed for each type of assigned work. While doing this, the injured body parts and accidents were classified. After the analysis, weighted scores for each type of accident were calculated. The SB availability is measured by Yes or No type checklist on the site investigation for each site.

3.5 Application of Fuzzy Operator

Linguistic terms are determined by the expert opinions and used to assign values (Pinto, 2014; Topal & Atasoylu, 2022; Zhang & Zou, 2007) to the SC, SB, AP, S, and RL presented in table 15. The fuzzy union/T-conorm/OR max operator is used to determine the effectiveness of each variable (SC, SE, AP, and SB), and the Fuzzy intersection/T-norm/AND min operator is used for the final risk level estimation (Pinto, 2014).

Table 15: Linguistic expression of variables and risk level.

Estimated Value (%)	Linguistic Variable
>80%	Very high
>60%	High
>40%	Average
>20%	Low
<20%	Very low

3.6 Application of Traditional Risk Assessment Model

The traditional RAM used, can provide a quantitative risk assessment based on historical data on risk levels of different work trades and accident modes. The risk levels of different work trades and accident modes prioritized by the RAM. The occurrence probability of an accident which is historical data collected also provides vital information for safety professionals to carry out a reliable risk assessment (Fung et al., 2010). No standardized risk levels are defined for work trades by the NC government.

3.7 Application of Preliminary Risk Assessment Model

There are three construction sites to evaluate the RAM model in the NC construction industry to determine the HI of each work trade and its attributes (Liu & Tsai, 2012). Pairwise comparison matrixes presented in table 3 were established using face-to-face interviews with these engineers for each type of work trade and their attributes using fuzzy numbers. The construction site is located in the city of Lefkoşa. They were randomly selected using excel software from a list of ongoing projects categorized based on three levels so that the study can be representative. The first site was a four-floor 1200 m2 apartment construction, at the carcass level, with 16 workers. The second site was a six-floor 2800 m2 building, at the finishing stage, with 40 to 60 workers based on the work done such as painting, window and door installation, waterworks, and woodworking. Moreover, the third site was a five-floor 1800 m2 building construction, at an intermediate stage such as brick wall building and plastering work. The education level of all workers ranged from no schooling to junior high school.

3.8 Application of FRAM

FRAM is applied in four small-sized construction industries in NC. Three construction sites were located in the city of Girne, and one was in Lefkoşa. The characteristics of construction sites are as follows:

1. A second floor and building maintenance work
2. Building a hospital
3. The construction of residences such as apartments and villas
4. The last site, located in Lefkoşa, was the business center construction.

There were site investigations of each construction site regularly. They identified each site's current situation to guide the experts to take preventive measures by considering the risk level (RL) determined by FRAM in NC construction industries. The variables are calculated step by step, and the final RL is determined using equation 21.

3.9 Application of Modified FRAM

Modified FRAM is the newly introduced model, and construction site one, mentioned in section 3.8, is selected for the application. The data was collected and used for this model. The final RL value is calculated through equation 22.

3.10 Application of MATLAB Program

RL of the construction site is determined by the defuzzification value obtained from the output of the fuzzy function of the MATLAB program (Gürcanli & Müngen, 2009; Kim et al., 2018; Patel & Jha, 2016). The MATLAB program uses four inputs: SC, S, AP, and SB, and the output is RL. RL is estimated faster using the MATLAB program (Topal & Atasoylu, 2022) by considering the initially defined 625 rules for each linguistic term. In order to increase the usage of the program, initially, pieces of training should be given to the site engineers for the MATLAB program. Then the rule files can be distributed accordingly. Expert opinions let the site engineers introduce the linguistic terms into the program to get defuzzification value for the risk level estimations.

Chapter 4

RESULTS

4.1 Results of Traditional Risk Assessment Model

The traditional RAM is used in this thesis to determine the risk level of each construction site by using historical data. Therefore, this model can be chosen in a way that there is no new information, and the construction engineers or safety professionals prefer to calculate the current situation at the construction site in the overall country. Determining the risk by historical data will highlight the current situation in the country, and the government representatives list managers' responsibilities in general by these results. According to the calculation, the following results are obtained and summarized for each work trade in table 16.

Table 16: Risks for each work trade

Work trade	Number of accident	Average LWD	Total number of LWD	SVI 1	F	Risk	%
Construction workers	107	34,12	3651	0,11	0,473	0,0538	45,07
Pattern maker	17	49,88	848	0,17	0,075	0,0125	10,47
Foreman	10	49,00	490	0,16	0,044	0,0072	6,05
Welder	10	44,10	441	0,15	0,044	0,0065	5,44
Painters	8	46,13	369	0,15	0,035	0,0054	4,56
Plasterers	12	30,00	360	0,10	0,053	0,0053	4,44

Driver/ Motorist	11	26,91	296	0,09	0,049	0,0044	3,65
Iron workers	10	22,70	227	0,08	0,044	0,0033	2,80
Builder/ Constructor	8	25,88	207	0,09	0,035	0,0031	2,56
Unknown	3	36,67	110	0,12	0,013	0,0016	1,36
Mechanist/ machine repairman	4	27,50	110	0,09	0,018	0,0016	1,36
Carpenter/ Furniture assembler	2	55,00	110	0,18	0,009	0,0016	1,36
Marble cutter	3	32,33	97	0,11	0,013	0,0014	1,20
Plumber	2	45,50	91	0,15	0,009	0,0013	1,12
Digger operator	1	90,00	90	0,30	0,004	0,0013	1,11
Ceramic layer	2	45,00	90	0,15	0,009	0,0013	1,11
Quarryman	2	45,00	90	0,15	0,009	0,0013	1,11
Security Guards	2	38,00	76	0,13	0,009	0,0011	0,94
Excavator operators	1	60,00	60	0,20	0,004	0,0009	0,74
Electricians	1	60,00	60	0,20	0,004	0,0009	0,74
Tile tiller	1	60,00	60	0,20	0,004	0,0009	0,74
Insulating worker	1	45,00	45	0,15	0,004	0,0007	0,56
Tire repairman	1	31,00	31	0,10	0,004	0,0005	0,38
Employer	3	10,00	30	0,03	0,013	0,0004	0,37
Repairman	1	30,00	30	0,10	0,004	0,0004	0,37

Concreters	2	10,00	20	0,03	0,009	0,0003	0,25
Aluminum workers	1	12,00	12	0,04	0,004	0,0002	0,15

RAM is modified, and risk is calculated for each type of accident by using different variables: the safety barrier index and LWD. In this model, the data was used collected from the Ministry of Labor from 2008 to 2013. The results obtained are summarized in table 17 below.

Table 17: Risks for each type of accident

Type of Accident	**SVI2**	**SVI3**	**F**	**Risk**	**Percentage**
Falls from height (FH)	0,0364	0,1236	0,4292	0,0687	44,48
Contact with machinery and moving parts (CM)	0,0199	0,1236	0,1814	0,0260	16,86
Struck by moving vehicle, including heavy equipment (S)	0,0322	0,1104	0,1549	0,0221	14,31
Compressed by equipment or objects (C)	0,0232	0,1236	0,0929	0,0136	8,83
Falls (F)	0,0349	0,1318	0,0619	0,0103	6,68
Traffic accidents(TA)	0,0467	0,1236	0,0354	0,0060	3,90
Falling from vehicle (FV)	0,0288	0,1647	0,0265	0,0051	3,32
Contact with electricity (CE)	0,0415	0,0988	0,0177	0,0025	1,61

According to the results obtained from traditional RAM, many hazards are associated with heights (RL=44.47%), followed by contact with machinery and moving parts

(RL=16.86 %). Moreover, a work trade with the highest risk level is obtained by construction workers (RL= 45.07%), and it is followed by the pattern maker (RL=10.47%). Special cares and concerns need to be undertaken for the high-risk activities.

4.2 Results of Preliminary Risk Assessment

Determining work trades is an essential step of HI determination for a given country as it mention in previous sections. Determining the work trades helps the researcher calculate the risk impact of attributes, HI, and ranking of attributes on selected three construction sites for this study, as shown in table 18,19 and 20 respectively by the developed model (Liu & Tsai, 2012).

Table 18: Risk impact of attributes, hazard index, ranking of attributes on hazard index for first construction site

Construction Site I					
Code	L	W	I	HI	RANK
A		0,408			
A1	0,674	0,275	0,767	0,21093	1
A2	0,226	0,092	0,900	0,08280	2
A3	0,100	0,041	0,700	0,02870	5
B		0,194			
B1	0,444	0,086	0,450	0,03870	4
B2	0,272	0,053	0,500	0,02650	7
B3	0,136	0,026	0,450	0,01170	10
B4	0,086	0,017	0,550	0,00935	12
B5	0,061	0,012	0,600	0,00720	14
C		0,175			
C1	0,610	0,107	0,500	0,05350	3
C2	0,190	0,033	0,500	0,01650	8
C3	0,134	0,023	0,500	0,01150	11
C4	0,066	0,012	0,400	0,00480	18
D		0,107			
D1	0,746	0,080	0,350	0,02800	6
D2	0,254	0,027	0,500	0,01350	9
E		0,058			
E1	0,439	0,025	0,350	0,00875	13
E2	0,268	0,016	0,300	0,00480	19
E3	0,143	0,008	0,450	0,00373	20
E4	0,098	0,006	0,300	0,00171	22

E5	0,052	0,003	0,258	0,00078	27
F		0,032			
F1	0,469	0,015	0,400	0,00600	15
F2	0,343	0,011	0,500	0,00550	16
F3	0,112	0,004	0,400	0,00143	24
F4	0,077	0,002	0,500	0,00123	25
G		0,027			
G1	0,485	0,013	0,400	0,00520	17
G2	0,297	0,008	0,358	0,00284	21
G3	0,138	0,004	0,400	0,00149	23
G4	0,080	0,002	0,400	0,00086	26
Overall Hazard Level				0,617	

Table 19: Risk impact of attributes, hazard index, ranking of attributes on hazard index for second construction site

Construction Site II					
Code	L	W	I	HI	RANK
A		0,189			
A1	0,093	0,018	0,850	0,015	14
A2	0,551	0,104	0,917	0,095	1
A3	0,356	0,067	0,600	0,040	4
B		0,323			
B1	0,419	0,135	0,692	0,094	2
B2	0,146	0,047	0,550	0,026	8
B3	0,126	0,041	0,500	0,020	11
B4	0,142	0,046	0,600	0,028	7
B5	0,167	0,054	0,550	0,030	5
C		0,157			
C1	0,036	0,006	0,500	0,003	25
C2	0,664	0,104	0,600	0,063	3
C3	0,118	0,019	0,600	0,011	15
C4	0,183	0,029	0,600	0,017	13
D		0,052			
D1	0,250	0,013	0,550	0,007	19
D2	0,750	0,039	0,550	0,021	10
E		0,087			
E1	0,035	0,003	0,500	0,002	27
E2	0,309	0,027	0,400	0,011	16
E3	0,185	0,016	0,567	0,009	18
E4	0,360	0,031	0,500	0,016	12
E5	0,111	0,010	0,500	0,005	21
F		0,096			
F1	0,105	0,010	0,358	0,004	22
F2	0,106	0,010	0,400	0,004	23
F3	0,128	0,012	0,300	0,004	24
F4	0,661	0,063	0,450	0,029	6
G		0,095			

G1	0,595	0,057	0,450	0,025	9
G2	0,134	0,013	0,400	0,005	20
G3	0,209	0,020	0,500	0,010	17
G4	0,063	0,006	0,400	0,002	26
Overall Hazard Level				0,624	

Table 20: Risk impact of attributes, hazard index, ranking of attributes on hazard index for third construction site

Construction Site III					
Code	L	W	I	HI	RANK
A		0,271			
A1	0,067	0,018	0,567	0,010	11
A2	0,749	0,203	0,900	0,183	1
A3	0,184	0,050	0,633	0,032	4
B		0,090			
B1	0,255	0,023	0,367	0,008	15
B2	0,117	0,011	0,433	0,005	20
B3	0,436	0,039	0,367	0,014	9
B4	0,069	0,006	0,500	0,003	25
B5	0,123	0,011	0,500	0,006	17
C		0,094			
C1	0,375	0,035	0,300	0,011	10
C2	0,393	0,037	0,567	0,021	8
C3	0,144	0,014	0,300	0,004	22
C4	0,088	0,008	0,300	0,002	26
D		0,119			
D1	0,152	0,018	0,300	0,005	19
D2	0,848	0,101	0,300	0,030	5
E		0,111			
E1	0,035	0,004	0,300	0,001	27
E2	0,171	0,019	0,433	0,008	14
E3	0,284	0,032	0,300	0,009	13
E4	0,096	0,011	0,300	0,003	24
E5	0,414	0,046	0,633	0,029	6
F		0,163			
F1	0,080	0,013	0,244	0,003	23
F2	0,330	0,054	0,756	0,041	3
F3	0,088	0,014	0,300	0,004	21
F4	0,502	0,082	0,700	0,057	2
G		0,151			
G1	0,429	0,065	0,367	0,024	7
G2	0,217	0,033	0,300	0,010	12
G3	0,195	0,029	0,244	0,007	16
G4	0,159	0,024	0,244	0,006	18
Overall Hazard Level				0,560	

Here even though the second site is the most hazardous (with the highest hazard level), the Kruskal Wallis Test shows no meaningful difference, as shown in table 21 by the mean hazard index. Hazard indexes are homogenous and have no significant hazard level difference between sites. The distribution of hazard levels based on the hazardous trades is summarized in table 22.

Table 21: Results of Kruskal Wallis test

	HR
Chi-Square	2.189
Df	2
Asymp. Sig.	.335

*p>0.05

Table 22: Distribution of hazard levels based on the hazardous trades

Hazardous trades	N	Minimum	Maximum	Mean	Std. Deviation
Scaffolding and ladder usage	9	,01000	,21093	,077492	,07381446
Construction tools and machinery	15	,00300	,09400	,021830	,02276253
Lifting and hoisting machinery	12	,00200	,06300	,018191	,01974508
Welding cutting and hot Works	6	,00500	,03000	,017416	,01059442
Excavation works	15	,00078	,02900	,007518	,00733019
Roof Works	12	,00123	,05700	,013346	,01852813
Concrete works	12	,00086	,02500	,008282	,00814565

According to the results obtained from preliminary RAM, the most hazardous work trade was found to be scaffolding and ladder usage with the attributes of volume, height, and design of scaffolding which is also related to the working with the high levels (Ak, 2020; Choe & Leite, 2017; Im et al., 2009).

4.3 Results of Fuzzy Risk Assessment Model

The FRAM can be applied by using the historical data and the newly collected data to determine the risk levels at the site to improve the safety measures and take the precautions to minimize the risk and provide a safer working environment (Fadier & De La Garza, 2006; Halperin & McCann, 2004; Leong & Shariff, 2008; Toole & Gambatese, 2008; Yassin & Martonik, 2004).

The aggregate current safety level in the construction sites was calculated to be 45.43%, which is "average" based on the fuzzy rules presented in table 15.

Weighted scores of each type of accident obtained from the checklists are presented in Table 23. According to the fuzzy rules possibility of an occurrence is "average" for accident modes F and FH and C and low for the other types of accidents.

Table 23: Weighted scores of modes of accidents.

Accident Modes	Weighted Score (%)
F and FH	42.85
FV and SMV	31.25
C	50.0
CE	28.57
CM and TA	23.33

The highest severity is associated with FH (49.30%), as shown in Table 24. The severity level for FH is "average" and "very low" for other types of accidents.

Table 24: Severity for each type of accident.

Modes of Accident	**LWD Index S**	**Occurrence Frequency Index F**	**Risk F × S**	**Percentage**
FH	0,0364	0,4292	0,0156	49,30
S	0,0322	0,1549	0,0050	15,74
CM	0,0199	0,1814	0,0036	11,39
F	0,0349	0,0619	0,0022	6,82
C	0,0232	0,0929	0,0022	6,80
TA	0,0467	0,0354	0,0017	5,22
FV	0,0288	0,0265	0,0008	2,41
CE	0,0415	0,0177	0,0007	2,32

Safety barriers obtained for the eight accident modes are presented in Table 25. The safety barrier for F and CE was "average," low for FH, SMV, C, CM, and TA, and very low for FV.

Table 25: Safety barrier percentages of accident modes.

Mode of Accident	**F**	**FH**	**FV**	**SMV**	**C**	**CM**	**TA**	**CE**
Safety Barrier (%)	45.00	37.50	8.30	22.90	22.90	37.50	37.50	40.00

Linguistic terms are used to describe the numerical values of variables and RL. The 625 fuzzy rules are developed considering the defined linguistic terms (Carr & Tah, 2001; Tah & Carr, 2000). The RL obtained by FRAM represents the minimum risk at each construction site and is presented in table 26. The risk level for FH is low and very low for other types of accidents. The low-risk level supports the need to maximize preventive measures and safety barriers to reduce risk further. In addition to RL results of FRAM, defuzzification values of RL estimated by the centroid method are presented in Table 27. Risk levels for each accident mode obtained by these two approaches are similar but not the same, as shown in Table26 and 27 respectively.

Table 26: Risk level evaluation using FRAM.

Accident Modes	Expected Severity (%)	Possibility of Occurrence of Accident Modes (%)	Current Safety Level (%)	Safety Barrier (%)	Ri(x) = Qand (SC, $S_i(x)$, $AP_i(x)$, $SB_i(x)$)
F	6.82	42.85	45.43	45.00	6.82
FH	49.30	42.85	45.43	37.50	37.50
FV	2.41	31.25	45.43	8.30	2.41
SMV	15.74	31.25	45.43	22.90	15.74
C	6.80	50.00	45.43	22.90	6.80
CM	11.39	23.33	45.43	37.50	11.39
TA	5.22	23.33	45.43	37.50	5.22
CE	2.32	28.57	45.43	40.00	2.32

Table 27: Defuzzification values of RL for each type of accident.

Accident Mode	F	FH	FV	SMV	C	CM	TA	CE
Defuzification value of RL	33.5	21.7	16.5	24.3	24.6	24.5	24.6	28.9

The FRAM and MATLAB program results are compared and summarized in table 28. This model uses fuzzy set theory to deal with uncertainty (Gürcanli & Müngen, 2009; Kim et al., 2018; H. X. Li et al., 2013; Q. Li et al., 2021; Mohandes & Zhang, 2019;

Taylan et al., 2014). Linguistic terms define the RL, and FRAM and FRAM MATLAB results are summarized in Table 28.

Table 28: Risk levels are defined by linguistic terms for FRAM.

Accident Mode	FRAM	FRAM with Defined Fuzzy Rules by MATLAB
F	very low	Low
FH	Low	Low
FV	very low	very low
SMV	very low	Low
C	very low	Low
CM	very low	Low
TA	very low	Low
CE	very low	Low

The current safety level represents the safety conditions at the construction sites. According to the analysis, SC is very low for all construction sites (site 1 is 14.29%, site 2 is 28.58%, and sites 3 and 4 are 14.29%, as shown in Tables 29–32). Similarly, Gurcanli and Müngen had similar results in 2009, and the safety level was found to be inadequate and average, with a score of 7.74. Therefore, the risk of an accident is very high, and the safety on-site should be improved. Pinto (2014) proposed that the safety climate at the construction site is awful since the value of safety climate was found to be 0.82, where 0 indicates an excellent safety climate.

Table 29: Results for site 1 by using FRAM.

Accident Mode	**S**	**AP**	**SC**	**SB**	**RL**	**MATLAB Results**
F	6.82	100.00	85.71	100.00	6.82	50.00
FH	49.15	100.00	85.71	100.00	49.15	50.00
FV	2.42	75.00	85.71	33.33	2.42	6.95
SMV	15.74	75.00	85.71	66.67	15.74	6.95
C	6.86	20.00	85.71	75.00	6.86	6.98
CM	11.53	46.67	85.71	75.00	11.53	7.24
TA	5.18	46.67	85.71	75.00	5.18	6.95
CE	2.30	71.43	85.71	40.00	2.30	7.26

Table 30: Results for site 2 by using FRAM.

Accident Mode	**S**	**AP**	**SC**	**SB**	**RL**	**MATLAB Results**
F	6.82	28.57	71.42	40.00	6.82	16.60
FH	49.15	28.57	71.42	25.00	25.00	16.70
FV	2.42	25.00	71.42	0.00	0.00	7.26
SMV	15.74	25.00	71.42	33.33	15.74	16.60
C	6.86	60.00	71.42	25.00	6.86	16.60
CM	11.53	13.33	71.42	25.00	11.53	16.60
TA	5.18	13.33	71.42	25.00	5.18	16.60
CE	2.30	14.29	71.42	40.00	2.30	16.80

Table 31: Results for site 3 by using FRAM.

Accident Mode	**S**	**AP**	**SC**	**SB**	**RL**	**MATLAB Results**
F	6.82	14.29	85.71	20.00	6.82	6.97
FH	49.15	14.29	85.71	0.00	0.00	7.36
FV	2.42	12.50	85.71	0.00	0.00	7.08

SMV	15.74	12.50	85.71	33.33	12.50	7.08
C	6.86	60.00	85.71	25.00	6.86	6.98
CM	11.53	13.33	85.71	25.00	11.53	7.24
TA	5.18	13.33	85.71	25.00	5.18	6.95
CE	2.30	14.29	85.71	40.00	2.30	6.81

Table 32: Results for site 4 by using FRAM.

Accident Mode	**S**	**AP**	**SC**	**SB**	**RL**	**MATLAB Results**
F	6.82	28.57	85.71	20.00	6.82	7.26
FH	49.15	28.57	85.71	25.00	25.00	7.36
FV	2.42	12.50	85.71	0.00	0.00	7.08
SMV	15.74	12.50	85.71	33.33	12.50	7.08
C	6.86	60.00	85.71	25.00	6.86	6.98
CM	11.53	20.00	85.71	25.00	11.53	7.24
TA	5.18	20.00	85.71	25.00	5.18	6.81
CE	2.30	14.29	85.71	40.00	2.30	6.81

According to the analysis, AP of falling from the same level and fall from height is very high, which means that the safety climate is low, safety barriers are ineffective, and severity is heightened. The sites' values are presented in Tables 28–32. According to the statistics summarized in this thesis, the most common type of accident is falls from heights. Accident likelihood was found to be high and frequent on the sites evaluated by Gurcanli and Mungen,2009. As a result of QRAM developed by Pinto, 2014 most serious possibility of accidents was falling with the value of 0.67. according to Papazoglu, 2017 for a specific work trade on fixed scaffolds, the highest accident risk rate is found to fall with recoverable injury.

The expected severity for each accident type is obtained using equation 20, and the results are summarized in Table 24 in section 4.3. The severity level for FH is measured as 49.30%, which indicates an average severity, which means that FH has the highest LWD and the highest occurrence of the types of accidents. The weighted score for severity value of less than 20% represents a low value for other modes of accidents, as shown in Table 24. Pinto (2014) recommended the maximum severity as one, and according to the results that obtained severity of falling from height is calculated as 1 and 0.58 for falling objects. According to Gurcanli & Mungen (2009), the highest severity was falling from a height, with the average score of 84 falling from severe to catastrophic. Fung et al. (2012) recommended that understanding the severity is essential to improve the safety at the site. According to Zhang & Mohandes, the highest severe accident type found falls from height at 0.1571, and the critically level is medium. Similarly, Zeng et al. found that severity is medium for the analyzed site.

The results of the safety barrier values vary from site to site since there is a lack of enforcement of rules and regulations and inadequate control mechanisms at the site. According to Pinto (2014), safety barrier effectiveness is insufficient for falls and falling objects, whereas excellent for contact with electricity.

According to the results of FRAM, it is concluded that the general site safety climate is very low. Safety barriers are inadequate and must be improved for a safer working environment. Especially for F and FH, safety barriers are too low, which explains why the highest accident probabilities are for those accident types. Similarly, the severity of FH is high. The severity of other accident types was found to be low. The accident possibilities vary from average to very high, as summarized in table 23. As a result, the risk level on site 1, FH, is average and very low for other types of accidents. Moreover, for other construction sites, the risk level was low for all accident modes. As explained in the formula, the risk level takes the minimum of all the variables, which shows the minimum risk at each site and needs maximum attention to minimize the risks.

4.4 Results of Modified Fuzzy Risk Assessment Model

The newly introduced variables are calculated and reflected in the FRAM. The modified FRAM was applied to the first site and the values are obtained accordingly. For the first site, the worker characteristics measure is calculated as 78.13%, where 100% indicates deficient safety at the work site, considering the employees' conditions and skills for a given job.

Moreover, the newly introduced second variable is the time of the activity. According to the site engineers, for a specific project, the working hours are more than ten, starting early in the morning till the afternoon before the evening. The site engineers should assign a number between 1 to 10 for the time of the activity, where 1 indicates a regular working hour within 8 hours and 10 indicates the overtime or nighttime situations. In this case, for the first site, the measured activity time is assigned as 70%, which is subjective since it is based only on the site engineer's perspective. Considering the values for the modified fuzzy risk assessment model, the risk will be determined for each accident mode and presented in table 33. Since the minimum of each variable determines risk, the final risk level value would be similar to the fuzzy risk assessment model. However, it will affect the managers' decisions since these two variables are calculated in a shorter implementation time, allowing the safety managers to take quick action on safety precautions and design their safety management systems accordingly.

The result is shown in table 33; the value of time of the activity is measured using table 5 in section 2.4.2.

Table 33: Results for site 1 by using modified FRAM.

Accident Mode	S	AP	SC	SB	W	T	RL
F	6.82	100.00	85.71	100.00	78.13	70.00	6.82
FH	49.15	100.00	85.71	100.00	78.13	70.00	49.15
FV	2.42	75.00	85.71	33.33	78.13	70.00	2.42
SMV	15.74	75.00	85.71	66.67	78.13	70.00	15.74
C	6.86	20.00	85.71	75.00	78.13	70.00	6.86
CM	11.53	46.67	85.71	75.00	78.13	70.00	11.53
TA	5.18	46.67	85.71	75.00	78.13	70.00	5.18
CE	2.30	71.43	85.71	40.00	78.13	70.00	2.30

As it mentioned in section 2.4.2., after the analysis, it is believed that the usage of personal protective equipment can be removed from the evaluation since it is not directly connected to the employee’s education that they gain. Then the worker characteristics measure is recalculated and found to be 58.33. Even if the risk level did not change, it has an essential effect on risk level calculation since the worker characteristic measure is high. Different scenarios can be developed which may affect the risk level;

Scenario 1. The experienced worker working day time then risk level is very low

Scenario 2. The experienced worker working nigh time then risk level is low

Scenario 3. The inexperienced worker working day time then risk level is high

Scenario 4. The inexperienced worker working night time then risk level is very high.

More scenarios can be created for different situations, which can be a guide for site engineers who will use risk assessment models developed in this thesis to determine the risk at site.

Chapter 5

DISCUSSION

This thesis aims to develop effective risk assessment models for the North Cyprus Construction industry to create a better working environment (Chan et al., 2010; Pinto, 2014; Toole & Gambatese, 2008) for employees by minimizing the accident risk at the site. The developed models can be used to determine risk levels for the construction sites and improve the safety measures on the construction site.

The result of this methods proves that the site’s risk is associated with the risk causes, which are the numerous factors increasing the risk of occupational accidents. Therefore, to determine risk, the site engineers should understand the nature of the accidents and their causes and reduce them by taking precautions (Ak, 2020; Carter & Smith, 2006; Hosseinian & Torghabeh, 2012; Namian et al., 2016). However, unfortunately before the accidents occur, most of the hazards or risks remain unidentified and uncontrolled (Albert et al., 2014; Fung et al., 2012; Karakhan & Gambatese, 2018; Namian et al., 2016). Thus, Fung et al. (2012) suggest the government to organize frequent trainings to construction managers and share the newest information with them.

Physiological and social factors affect the workers' performance and productivity. Working in a stressful environment is not easy and reduces worker performance, thus increases accidents in the working environment. Risk can increase because of the variety of cultural, economic, and environmental differences among employers at the site (Zhang & Zou, 2007). For this reason, new variables are included in the developed models, such as worker characteristic (Maqsoom et al., 2018). Therefore, it is essential to consider these variables in the risk assessment models to determine the risk accurately.

Additional interventions may include motivational management actions such as safety training, safety supervision and encouragement of the workers to use protective equipment, rewards for compliance with recommendations, improving job satisfaction with an increase in salaries, and carrier development approaches (Albert & Hallowell, 2012; Eskandari et al., 2017; Karakhan & Gambatese, 2018). Educational interventions can help workers relate the information gained to their work experience and, as a result, work will be safer (Albert & Hallowell, 2012).

The preliminary risk assessment model developed in this study can quickly help identify site-specific risks and hazard levels which can guide the design of safety programs. The sites included in the preliminary risk assessment model are considered as representative samples since our observations show that working conditions at North Cyprus construction sites do not vary immensely. Therefore, one limitation is the inability to identify the differences between construction sites, given the small number of sites and engineers included in the study.

However, results of the preliminary risk assessment model show that the construction companies had difficulty taking preventive measures since all three overall hazard levels were high. One of the reason may be the lack of enforcement of the North Cyprus occupational safety and health law (Işık & Atasoylu, 2017). In contrast, another important reason may be the lack of awareness of the site-specific severe risks. Site-specific hazard assessment results of different work trades and their attributes represent real-time data rather than an abstract calculation, which can motivate employers to invest in construction site safety measures.

There is no significant difference in overall hazard levels determined in this study for the three different construction sites. Therefore, we can conclude that the workforce level, operating platform, and stage of the construction do not directly affect the risk level of hazards at the construction sites. According to this, in North Cyprus, construction workers work in hazardous environments at each stage.

Fuzzy risk assessment model differs from other methods in that aggregated weighted scores are calculated for each parameter in the model. There are several advantages of fuzzy risk assessment model, but in addition to all, it is not complicated, and it is an effective model which can be applied to the small size construction industry in North Cyprus and elsewhere that share the same characteristic environment. According to the results obtained from fuzzy risk assessment model, even if the risk level is low, the possibility of occurrence should be minimized by taking preventive measures, and safety barriers should be maximized. According to the observation, the safety climate is higher for the more extensive construction site. Safety barriers are more for the urban area. The percentage occurrence of fatal accidents is higher for new workers. The reason is the lack of occupational health and safety inspection and enforcement. The methodology could be improved for modified fuzzy risk assessment by calculating the severity at the site rather than using historical data.

Likely in North Cyprus construction sites, Zhang and Zou (2007) found the risk condition at a severe level and suggested contractors take appropriate risk management strategies earlier (Zou et al., 2007) to deal with risky conditions at the site. Pinto (2014) mentions that the highest risk level value is 0.68 for falls and suggested prioritizing precautions starting from the causes of the highest accident types. Mohandes and Zang (2019) proposed that falls from height are one of the sub factors with the highest threatening risk factors at site, considering both the probability and severity measures like in the North Cyprus construction industry. Liu and Tsai (2012) presented that one of the most common hazards is the falling and collapse of objects. In addition, Liu and Tsai (2012) mention that the hazard causes are improper usage of facility and construction management and unappropriated safety materials used at the site.

Larionov et al. (2021) argued that there is no acceptable risk level and no tolerable risk at sites, highlighting the importance of risk and safety management. The study by Zavadskas et al. (2010) presented that risk levels at construction sites can be calculated using different approaches, and the order of the risk level may vary from site to site.

Risk reduction actions should be determined for hazard types and with suggested safety barriers, according to Papazoglu et al. (2017). Dikmen et al. presented that the risk level is medium to medium to high. Worker experience and contract conditions are influenced factors of the risk model developed by Dikmen et al. The study by Zeng et al. concluded that risk magnitude is between minor and significant. The results presented by Gurcanli and Mungen (2009) show that falling from height has the highest risk level value. Topal and Atasoylu (2022) stated that the highest risk level is for falling from height with the highest probabilities of occurrence. As a result of this risk level determination approach, the main aim is to reduce the risk level to a low or no risk area, according to Gurcanli and Mungen (2009). Similarly, in our study we found that falling from a height has the highest risk. The worst dimension is the safety climate, followed by worker characteristics, time of the activity, accident possibility, safety barrier, and severity.

In general, site safety is essential in the construction environment. For instance, construction site warning signs should be put in the appropriate place. The job should be done by skilled labor (Aneziris et al., 2012). Special rules for scaffolds should be followed, and the strength and durability of scaffolds should be calculated. Employers should supply necessary protective equipment to employees without any charge. Employers should train their employees well, and those training should be repetitive to protect employees from illnesses and injuries.

Safety barriers suggested for falling from the height, which has the highest accident rates, are harness, guard rail, safety net, and proper scaffolding design (Aneziris et al., 2012; Topal & Atasoylu, 2022). Therefore, there must be more safety barriers for employers working at a height. The current safety barriers should be improved, and new measures should be taken. In addition, it has been suggested that qualified employers should be assigned to the jobs with higher risks (Aneziris et al., 2012). In conclusion, significant investment should be made to reduce the risk of falling from a height at sites (Im et al., 2009).

Furthermore, the machines and equipment used in working places should have warning signs, and employers should provide written instructions about the machines and equipment. According to the observations, employees do not use personal protective equipment regularly; there is no warning sign to ensure that people cannot come to the construction site. There are no appropriate protectors to protect employees from possible falls. The employees do not use foot protectors or safety harnesses while doing the specific work. In addition, employees are not protecting themselves from a harmful level of external factors such as noise and dust.

The results show that the safety climate is generally very low. Safety barriers are inadequate and should be improved. Exceptionally very low for falls and falling from a height, which explains why the probability of occurrence of these types of accidents is high (Ak, 2020; Larsson & Field, 2002; Lingard, 2002; Topal & Atasoylu, 2022). The probability of occurrence of each type of accident changes from very high to average. The severity of falling from a height is high and low for other types of accidents.

There are some limitations on this study which are the number of variables used in the model can be increased by considering the suggested variables in previous chapters. Age motivation and the experienced number of years of the workers are few. The lack of a training program so that the model can be introduced to the safety professionals. The lack of worker characteristics for a specific job is not calculated; instead, the general worker characteristics information is collected simultaneously. The time of the activity measure only depends on the site engineers' perspective, which may need to improve in further studies. The lack of language used at the site sometimes requires more time to collect information from workers. The family-owned industries are all private, and it is not easy to get any information related to safety.

The project completion time and the budget constraints factors have impact on the construction management (Kuo & Lu, 2013), and these variables should be considered in the further study. There are different costs that we can link to the construction site; risk methods, such as recovery fees, replacement factors of skilled labor required for a specific job, training costs, and costs that occurred because of the accident. The modified fuzzy risk assessment model can introduce the cost factor since it is essential for the companies. In addition to that the project size and location factors can also use in modified fuzzy risk assessment model. In North Cyprus, we only consider small industries, but project size can affect the risk measures at sites for different countries. Moreover, the site's location in rural and urban areas can make the safety measures challenging to control.

Teo and Ling (2005) presented that construction safety management is based on four variables which are: Policy (such as rules and regulations, occupational health and safety standards and procedures), the process of the work (such as machinery, equipment usage, and site conditions), personnel (such as safety culture and training) and incentives (such as safety incentive programs). They should also consider the construction safety management approaches listed above. The resulting risk and hazard obtained by the developed models will help safety managers provide a better working environment for the construction workers by reducing the risk at the site.

Chapter 6

CONCLUSIONS

North Cyprus is a developing country with rapidly increasing construction sites (North Cyprus State Planning Organization, 2017). Therefore, there is a growing need for a helpful approach to identify and evaluate onsite hazards and their risk levels. Managers (employers) and safety professionals (or engineers) play an essential role in providing safety on construction sites (Eskandari et al., 2017). This study provides an essential tool to the experts, safety professionals, or site engineers responsible for performing the risk assessment at the site.

My detailed literature review highlighted the factors contributing to an effective risk assessment model development. Safety professionals gather the historical data available in the Ministry of Labor to categorize, and organize it. This study will guide the safety professionals in North Cyprus industry to understand the current situation at the sites. In the developed risk assessment models, historical data is used to determine the severity and possibility for all construction sites and work trades. The preliminary risk assessment model which is developed by Patel et al. (Patel & Jha, 2016) is modified in a way that it is applicable to North Cyprus industry. The work trades and their attributes change fast throughout a construction project timeline, making it challenging to identify and act on new hazards. Thus, the work trades and attributes are revised by considering the accident investigation reports for North Cyprus construction industry. After implementing the model several times, the authors decided to use the overall hazard value as the preliminary risk assessment model to identify the most hazardous construction site.

The modified fuzzy risk assessment use linguistic variables to overcome difficulties such as subjectivity in representing the values for each variable (Gou et al., 2021; Gul & Ak, 2018; L. A. Zadeh, 1975).The error which may occur in the data is eliminated by using the fuzzy approaches to the model. The model developed by Pinto (2014) uses 4 variables in the model. In order to increase the effectiveness of the fuzzy risk assessment model the new variables have been added to the developed model. Our model uses six variables to calculate the risk at site which is the main advantage. The way of calculating each variable in the model is modified by the authors to make the model applicable in NC industry. Another advantage of the modified fuzzy risk assessment model is, the risk calculated for general construction sites, not only on the specific site jobs. The excel file is also prepared so site engineers can calculate the values for each variable and determine the risk for each site. The purpose of the excel file in this study is, in North Cyprus, the checklist can be distributed to the site engineers online and then asked to fill the checklist accordingly. Then for each site, the aggregated values will be calculated automatically by the excel spreadsheet. This way, the results can be obtained faster than face-to-face interviews. The only drawback is that by the site visits, safety professionals can also check the current situation at the site. It is suggested by the authors to modify the checklist questions (for safety climate, accident possibility, and safety barrier variable) considering the rules and the regulations in other countries even though they do not share similar properties of the North Cyprus construction industry. In the North Cyprus industry, the sites are small-sized construction industries with no enforcement, no regular training, and no enforcement of on-site investigations.

On site visits, our observation is that employees of the North Cyprus construction sites have low education levels, which may negatively affect their occupational health and safety. The health and safety professionals or engineers are not always present on the site; they leave after assigning the tasks for the day. Therefore, it is not always possible to follow and take immediate action when safety is compromised. Thus, the need of worker characteristic measure is necessary. As a result of our calculations, the effect of the worker characteristic measure on risk calculation is high.

The developed model uses time of the activity as an important measure since the workers are expected to the work more than the regular working time. The authors, uses subjective decisions of engineers on this measure. This should be revised in further studies.

MATLAB results and the results obtained by the model are compared, and the order of the risk is found to be identical. However, the access to the program will not be easy for site engineers. The authors suggested to have training on this issue for site engineers who will conduct the risk assessment models. Alternatively, excel spreadsheet can also be used to obtained aggregated value for each variable when the required expertise to use the program is not present.

The results obtained for each variable and the final risk values conclude that the North Cyprus construction industry needs immediate attention and offers an essential tool for rapidly eliminating deficiencies at construction sites. Unfortunately, there is a gap between theory and practice, and no similar study has been found in North Cyprus literature. We should add a control mechanism to measure the risk and reduce the risk as much as possible.

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APPENDICES

Appendix A: Comparison of RAMs

Table A1. Comparison table

Study	Applied Method	Parameters for Risk Calculation	Used Evaluation Method	Advantages	Disadvantages
(Teo et al., 2005)	Multi Attribute Value Model	Policy, process, personnel incentive factors	AHP to Weight and rate of each attribute and factorial analysis. The construction safety index is calculated by using this method.	Its increased the effectiveness of the safety management system.	The number of participants is few and only considers the rules and regulations of a given country.
(Zou et al., 2007)	Fuzzy AHP	Risky condition factor assessment, risk groups: internal, project specific, external.	Weight vector, linguistic terms, then select the maximum value.	Quantitative values are obtained for this type of case.	Technical and financial risks are not considered.
(Dikmen et al., 2007)	Influence diagram, Fuzzy Risk Assessment	Fuzzy risk rating together with influence diagramming method for risk identification.	If-then rule	The influence diagram and fuzzy set theory are used at the same time.	If then rule for computerized models used only for cost overrun.

(Zeng et al., 2007)	AHP	Human, site, material, and equipment factors.	Fuzzy reasoning technique, Risk likelihood, risk severity, and factor index.	Three variables are used in the model to determine the risk.	More variables can introduce to the model.
(Gürcanli & Müngen, 2009)	Fuzzy Rules	Site conditions, accident types, safety items and factors, external factors.	Risk likelihood, accident severity, and safety level.	Linguistic terms are used; determining the current safety level for each site is essential since past data is unreliable.	Focus only on daily activities, not on the whole process; financial issues are not considered.
(Fung et al., 2012)	Delphi Technique	Insufficient management control, unsafe practice, substandard conditions, personal and job factors.	Probability and severity are used to calculate risk level for each work trade.	Accident statistics collected by the quantitative and qualitative method.	To calculate probability, they cannot use LWDs since it is not recorded.

(Liu & Tsai, 2012)	A Fuzzy Analytical Network Process	The factors are the probability of occurrence, the severity of the failure, and the probability of not detecting the failure.	Severity, If then rules, linguistic terms, triangular membership functions, and risk level.	Semi quantitative approach	Other fuzzy numbers can be used instead of fuzzy triangular numbers.
(Zavadskas et al., 2010)	TOPSIS Grey and Copras G.	Decision-making matrices, risk groups: internal, project, and external.	Aggregated values are calculated and then ranked for the site.	Decision-making approaches allow evaluating the attributes to choose the best one.	Only expert opinions are used.
(H. X. Li et al., 2013)	Fuzzy AHP	Project cost, duration, risk groups: general, in-plant, and onsite.	Simulation, t-distribution, Chi square, and triangular fuzzy membership function.	Modular construction is not for conventional onsite construction.	A long implementation time is required.
(Kuo & Lu, 2013)	Multi criteria decision-making method, consistent fuzzy preference relations matrix	Engineering design, construction management, construction safety related, natural hazards, social and economic factors.	Risk is calculated by multiplying the impact of the factors and the probability of occurrence.	Use a consistent fuzzy preference relationship matrix instead of AHP.	Only expert opinions, the limited number of participants.

(Pinto, 2014)	QRAM	Safety barriers, safety climate, severity, and accident possibility factors.	A fuzzy intersection is used to determine the risk value.	More variables are considered compared with the previous models.	The severity and safety climate's weight can be calculated using different approaches.
(Papazoglou et al., 2017)	Influence diagram	Create an event, recoverable, permanent, and fatal injuries, and support safety blocks.	The probability of safety barriers and expected frequency of accidents are calculated.	An occupational accident rate for each worker exposed to a specific hazard is determined.	A single hazard model is developed.
(Mohandes & Zhang, 2019)	Modified Delphi Technique	Safety, ergonomic and chemical factors are used.	Risk is calculated by multiplying the probability and severity.	Straightforwardly analyze the risk by considering the severity and probability.	The model is developed for only elevator maintenance.
(Larionov et al., 2021)	Monte Carlo Method	The factors which affect the environmental safety in the construction area are considered.	Risk is calculated by multiplying probability and expected damage. The probability function curve is also used in this model.	It is the first time that this method has been used.	It is not easy to apply the method.

(Topal & Atasoylu, 2022)	Fuzzy AHP	Warning signs, instructions, ergonomic and physical hazards, environmental level, and checklist	Accident possibility(checklist), current safety level(checklist), safety barrier (checklist), and severity(historical data on the number of accidents and LWDs is used) are used to calculate the risk.	Linguistic terms, Fuzzy AHP, and historical data are used at the same time. FRAM can be applied by the site engineers very easily.	More variables can be added.
Modified FRAM	Hazard Index and Fuzzy AHP	In addition to the FRAM, worker characteristics and time of the activity variables are added.	Hazard index and fuzzy AHP model are used to calculate the risk at the site.	It has more variables compared to the RAMs available in the literature.	Different techniques can be used to calculate the weights. Moreover, different membership functions can be used in the model.

Appendix B: Preparing Checklist to Determine Current Safety Level (Topal, 2011)

Table A2. 0.04 Part A. Warning signs and instructions.

	YES	NO
1. Is there any sign or security color in the workplace which has a risk for obstacles and falls?		
2. Is there any illuminated sign in places that require voice signal and verbal communication?		
3. Is there any written instruction about the equipment that is used by employees?		
4. Is there any warning or sign on the equipment's which is necessary for employee protection?		
5. Is there any measures taken for protect the employees falling from the greasy ground at the workplace?		
6. Is there any sign used for incomplete scaffolding?		

Table A3. 0.62 Part B. How often employees are confronted with the following.
1: Always, 2: Often, 3: Sometimes, 4: Rarely, 5: Never.

1. Load carried
2. Incorrect handling
3. Personal protective equipment (used regularly or not)
4. Stairs in the construction area
5. Head protectors while you are working on scaffold, high platforms or below people working above you
6. Positioning rope
7. Protectors to protect from possible falls (scaffold, rope)

Table A4. 0.24 Part C. Ergonomic and Physical Hazards (low to high).

	1	2	3	4	5
1. How often are employees confronted with repetitive movements?					
2. How often are employees confronted with static exposure?					
3. How often are employees confronted with overload?					
4. How often are employees confronted with vibration?					
5. How often are employees confronted with tighten hand or arms? Clarify—what is tighten hand or arms?					
6. How often are employees confronted with dusty area?					
7. How often are employees confronted with unventilated area?					

8. How often are employees confronted with noise?

9. How often are employees confronted with humidity?

Table A5. 0.10 Part D Environment Level.

	YES	**NO**
1. Temperature (Normal Level 19.2–22.8 0C)		
2. Humidity (Normal Level 45%–65%)		
3. Noise (Normal Level ≤ 80 decibels)		
4. Illumination		
5. Ventilation/Dust		
6. Lighting		
7. Vibration		

Appendix C: Preparing Checklist to Estimate the Effectiveness of Safety Barriers

Table A6. 0.10 Safety Barrier checklist

Accident Modes	SB Measures	YES	NO	
Falls	Fixed Standard Railings			1. Excavation
	Good house keeping			2. Construction of walls foundation
	Cover the holes			3. Cement pouring into molds
	Boot			4. Removal
	Hard Hat			5. Scaffolding
Falling from height	Harness			1. Excavation
	Guard Rail			2. Construction of walls foundation
	Safety Net			3. Cement pouring into molds
	Proper scaffolding			4. Removal
				5. Scaffolding
Falling from vehicle	Safety Belts			1. Excavation
	Training			2. Construction of walls foundation
	Operating Instructions			
Struck by moving vehicles	Hard Hat			1. Excavation
	Goggles			2. Construction of walls foundation
	Special Gloves			
	Operating Instructions			
	Separating work areas			
	Barriers			
Compressed by moving objects	Special Gloves			1. Excavation
	Hard Hat			2. Construction of walls foundation
	Safety Boots (toe guard)			
	Operating Instructions			
Contact with machinery	Special Gloves			1. Cement pouring into molds

	Hard Hat Personal Protective Equipment Machinery guards	2. Cut steel rebar
Traffic Accident	security belt lights PPE	
Contact with electricity	Non-Conducting Boot Safety Working Procedure Proper maintenance Lock out and tag out Gloves	

Appendix D: Preparing Checklist to Estimate the Possibility of Occurrence of Accidents

Table A7. Checklists for possibility of occurrence of accident modes (Pinto, 2014)

Falls and Falling from height	YES	NO
1. Are there fixed stairs protecting against falling from either side?		
2. Proper measures are taken so that employees perform built-up roofing work to protect from falling from the roof's side edge of the roof?		
3. Are the portable ladders used only in short-term jobs and do not require the worker side loads?		
4. Are the scaffolds adequate, meet the requirements, are regularly inspected, and kept in reasonable condition?		
5. Is the work environment clean, with floors and access routes clear of obstacles, and are the aisles and passageways clear and in good repair?		
6. Are the workers wearing proper personal protective equipment?		
7. Are the workers using safety line harnesses?		
Falling from vehicle and Struck by moving vehicle, including heavy equipment and Traffic accidents	YES	NO
1. Do all visiting drivers report to site management before entering the site?		
2. Are the vehicles maintained to ensure that the steering, handbrake, and footbrake work properly?		
3. Are there physical speed restrictions?		
4. Are the vehicles securely loaded and without overload?		
5. Are the passengers prevented from riding in dangerous positions?		
6. Are any vehicles left without being properly locked?		
7. Are there any signs or barriers separating work areas?		
8. Are there any written instructions about the vehicles used on the site?		
Compressed by equipment or objects	YES	NO

1. Is there any practical training about how an employee should use personal protective equipment?		
2. Are there any warning signs on the equipment necessary for employee protection?		
3. Are there any warning signs on the machines necessary for employee protection?		
4. Are there any warning signs on the vehicles necessary for employee protection?		
5. Are there any written instructions about the machines and equipment used on the site?		

Contact with electricity	YES	NO
1. Has the electrical equipment been revised before being reassembled in a new site?		
2. Do the workers not wear metal objects when working with electrical devices?		
3. Are the metal ladders not used when working on or near electrical equipment?		
4. Are the workers using proper safety boots that do not conduct electricity?		
5. Are the workers using proper personal protective equipment?		
6. Are they applying lockout-tagout procedures when maintaining equipment in the worksite?		
7. Is there any training about the hazards and procedures in the site while working with electricity?		

Contact with machinery and moving parts	YES	NO
1. Are work areas well dry, and clean?		
2. Are vehicles securely loaded?		
3. Are proper guards installed on machines to protect workers?		
4. Are machinery guards kept in place and in working order?		
5. Are hand tools and other equipment regularly inspected for safe condition?		
6. Are frames of all arc welding and cutting machines appropriately grounded?		

7. Are all employees performing any welding, cutting, or heating protected by suitable eye protective equipment?

8. Are power tools, belts, gears and chains adequately guarded?

9. Is there any training about how employees should use personal protective equipment?

10. Are there any warning signs on the equipment necessary for employee protection?

11. Are there any warning signs on the machines necessary for employee protection?

12. Are there any written instructions about the equipment used on the site?

13. Are there any written instructions about the machines used on the site?

14. Are the employees aware of the hazards of all types of equipment and machines that can affect them even if they did not use them?

15. Are machines and equipment are appropriately fixed?