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A Fuzzy Risk Assessment Model for Small Scale Construction Work

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Abstract: Occupational risk assessment is important for providing employees with a safe and healthy work environment. When compared with other industries, the construction industry poses a higher risk for accidents due to the variety and complexity of skills required for different types of work in the sector. Small-sized construction sites have a higher risk of occupational injury. Countries without occupational safety and health (OSH) enforcement pose an additional risk increasing the need of an effective and easy-to-apply risk assessment approach. This research aims to develop and study an easy to apply risk assessment model for small-scale construction sites. The method includes opinions from experts on safety, checklists to estimate the possibility of occurrence of accidents, the identification of current site-specific safety levels, the severity of risk, and safety barriers. The model uses both historical data and fuzzy approaches to calculate risk level and was applied to four different construction sites in North Cyprus. Results reveal the risk level for each accident type and the aggregate safety level of the construction sites. Falling from height was identified as the most common accident type with the highest risk level. This study contributes to the development of sustainable OSH management systems for construction companies by highlighting the measures that must be taken to reduce occupational accidents.

Keywords: occupational health and safety; risk assessment; fuzzy risk assessment model; risk level; construction industry

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1. Introduction

The construction industry has the largest number of injuries compared with other industries. This can be explained by the high-risk nature of construction work. Low education level of workers, poor working conditions, the broad skills required for varying job tasks, and the use of different tools, equipment and machines all contribute to an increased risk of occupational injury and illness [1–6]. Additionally, because construction workers often change their work location [4,7] this also increases accident risk. Companies must have an effective approach for identifying and reducing the occupational risk. It has been well established that one of the most effective ways to improve safety performance, including accident prevention, depends on the reduction of risk uncertainty [8,9]. Risk analysis is the key to identifying risks and taking preventive measures. Models for risk assessment assist safety professionals in assessing the risk of work-related accidents. These models also help workers understand the risks associated with the various types of work [8].

North Cyprus is a developing country with a rapidly expanding construction industry. OSH regulations are not enforced [10,11] leading to unregulated construction and the lack of sustainable OSH management systems. According to data from the North Cyprus Ministry of Labor and Social Security, there is a growing number of occupational accidents. The construction industry has been identified as being in need of attention with the highest number of occupational injuries including fatalities in the last 10 years [12]. Falling from height is found to be the major reason for most fatal construction accidents in North Cyprus, as it also is worldwide [13].

Small- and medium-sized companies are at increased risk for occupational injuries when compared with large companies. In North Cyprus, more than 95% of private organizations including construction firms are small- and medium-sized businesses and 89% of these are family-owned [14]. Consequently, work tasks are not assigned according to worker skill. Task assignment should be carried out by experts who are well-trained in OSH [15], in order to reduce occupational accidents [15–17]. To reduce accident rates, the appropriate safety barriers for each type of accident should be identified [18] and shared with the on-site safety manager. Prevention of occupational accidents for small construction enterprises relies on several factors including employers' values regarding health and safety, their management skills, and enforcement of safety laws and regulations [19]. The high rate of occupational injuries and lack of enforcement of OSH regulations invoke the need for effective, easy-to-apply risk assessment models for the construction industry.

The objectives for this study were to develop a simplified risk assessment model that is easy to apply at small scale construction sites and to study the effectiveness of this model. By effectiveness we mean does it perform as well as more complicated, difficult to apply risk assessment models. The motivation for this work is the knowledge that small-scale construction companies are less likely to perform risk assessment and one of the reasons for this may be time and resources. The authors believe this modified risk assessment model using linguistic variables is more likely to be utilized by the small-scale construction companies. The potential impact of this work is the development of sustainable OSH management systems in the construction industry in North Cyprus and similar developing countries.

The remainder of the paper is structured as follows: literature review, materials and methods, data analysis, results and discussion followed by conclusions and recommendations for future research.

2. Literature Review

Many factors affect the construction industry's risk assessment model selection. Different qualitative and quantitative risk assessment models [20,21] can improve safety at the site by encouraging decision-making in safety programs [22]. Some of these models were developed using historical accident data [8,23] to determine risk at different stages of construction sites and by considering the various types of work tasks [4,24]. All records on accidents are collected and evaluated in this study to overcome difficulties in understanding the current situation at the site [25]. There are some drawbacks, such as uncertainty and incompletion, to using completely historical risk assessment models; therefore, fuzzy approaches are preferred to determine the risk at the site [18].

Another helpful approach is the analytical hierarchy process (AHP) which helps determine weights [26] for different risk factors. The advantage of AHP is to reduce the experts' decision-making errors in evaluating the alternatives at the site [27]. Experts can use fuzzy linguistic terms to make comparisons between each risk factor [28–31], and the center of the area method is used for defuzzification [28]. This way, the approach for the expert is simplified and a model deals with the numerical evaluation of the risks. There might be a complicated pairwise comparison matrix required for big projects, which takes a long time to implement, making this system difficult to use [27]. The Fuzzy technique for order of preference by similarity to ideal solution (TOPSIS) method can be an alternative to the analytical hierarchy process. The only difference between the two methods is that positive and negative ideal solutions can be calculated with the fuzzy TOPSIS method. The fuzzy TOPSIS method is efficient and easily applied on the site. It uses extended, vague linguistic terms that site engineers can easily use, and as a result, it selects the closest alternative to the positive ideal solution [32,33].

Fuzzy association and fuzzy composition are applied to determine the connection between the suspected risk source and the risk level outcome for a site [34]. The fuzzy if-then rules are used to improve the results obtained by the standard calculations [35]. A Qualitative Occupational Safety Risk Assessment Model (QRAM) was developed for the construction industry that deals with uncertainties using fuzzy sets [9,36]. Fuzzy set theory helps develop precise models to reach more robust results. The QRAM model can be improved by simplifying safety climate and severity variables [36].

Fuzzy logic can define the relationship between risk, the risk factors, and their effects. Lotfi A. Zadeh first introduced fuzzy logic when they stated that "a fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership function which assigns each object a grade of membership ranging between zero and one" [37,38]. Fuzzy rules are defined, and fuzzy membership functions are generated using linguistic terms [8,34,39–41]. Fuzzy set theory helps the researchers to manage uncertain situations and deal with vagueness [42]. The triangular fuzzy membership function is used since it is the most commonly used one in construction project risk analysis applications [41,43]. Other fuzzy membership functions can be used, making the system more appropriate and allowing further research to suggest the use of different fuzzy functions to choose the suitable one [35].

In general, a variable takes numbers as its value. If a variable is classified according to the categories of values, e.g., very high or high, then it will be called a linguistic variable [44]. In this study, linguistic expressions are used to assess safety climate factor (SC), possibility factor (AP), severity level (S), safety barrier (SB), and the occupational risks for workers at a construction site [24].

3. Materials and Methods

In this study, the risk level of construction sites is evaluated using Equation (1). This equation was published by Pinto (2014) and was introduced as a qualitative risk assessment model (QRAM) with four variables used to estimate the risk of accident modes, namely: Safety Climate (SC), Possibility Factors (AP), Safety Barriers (SB), and Severity Factors (S). 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 level of the construction site (SB), and the severity of each type of accident mode (S). The Fuzzy AND operator is used to estimate the minimum risk level for each accident mode through Equation (1) [36].

$$\mathrm{Risk}\ (\mathrm{x}) = \mathrm{Qand}(\mathrm{SC}, \mathrm{Si}(\mathrm{x}), \mathrm{APi}(\mathrm{x}), \mathrm{SBi}(\mathrm{x})) \tag{1}$$

The Fuzzy risk assessment model (FRAM) established in this study is a model based on Equation (1) that brings simplicity in application compared to QRAM. It has a new and more straightforward approach to determining the variables and has been successfully used to estimate the risk levels of four different construction sites in North Cyprus.

3.1. Use of Historical Data

Historical data were used for categorizing accident types, identifying severity, and identifying related work trades. Statistical data of accident modes is essential for understanding specific risk factors in the North Cyprus construction industry. Historical accident data were collected from the North Cyprus Ministry of Labor and the Social Security Department of Labor by reviewing the 2008–2013 accident investigation reports. Work trades were identified, accident and injury types were categorized, and the lost working days (LWD) for each type of accident were calculated. Severity levels were based on the number of LWDs.

3.2. Determination of Current Safety Level and Accident Risk

Two types of checklists were prepared to determine the current safety level and the possibility of accident modes at construction sites. The checklists are presented in Appendices A and B. Questions were prepared based on North Cyprus OSH regulations for SC [6,45,46], and professional opinion was used to modify the previously published checklist [36] for the NC construction industry identify SB. In order to determine the weight for each part of the SC checklist, the AHP was used. AHP, introduced by Thomas Saaty

(1980), is an effective tool for decision making using pair-wise comparisons and setting importance to each item [47].

3.3. Determination of Barriers to Safety

Work tasks were analyzed to determine the site's hazards and types of accidents and SB's preventive measures for each work task. Table 1 was prepared to estimate the safety barriers' effectiveness. In this table, each accident mode injured body part obtained from the accident investigation report is listed with the number of the accident reported. According to that, possible preventive measures are listed to suggest the construction industries at the end of the study. After several interviews and site investigations, work trades are listed for each type of accident mode [26].

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) Trunk/Back (2)	Fixed Standard Railings Good house keeping Cover the holes Boot Hard Hat	1. Excavation 2. Construction of walls foundation 3. Cement pouring into molds 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 my 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) Hand/Finger (24) Trunk/Back (1) Other (4)	Special Gloves Hard Hat Personal Protective Equipment Machinery guards	1. Cement pouring into molds 2. Cut steel rebar

Table 1. *Cont.*

Accident Modes	Injured Body Part (Number of Accident), Preventive Measure, Work Trade		
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	

3.4. Determination of Accident Severity

For each construction site, accident severity is determined by using Equation (2). 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, lost working days are used as an indicator to get the severity of accidents [8].

$$\text{Severity} = \text{F} \times \text{S} \tag{2}$$

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

3.5. Final Estimation of Variables and Risk

The risk level of each accident mode is determined by Equation (1). This highlights the risk level of the construction sites by using historical data, site investigations, and experts' opinions. The minimum risk level shows how much attention should be given to each accident mode. Furthermore, fuzzy rules and membership functions were created with the MATLAB program. The results obtained from FRAM and the program were compared, and the results are accurate and reliable.

4. Data Analysis

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

After reviewing the North Cyprus construction industry accident reports (2008–2013) obtained from the labor office, eight different types of accidents and 27 work trades were identified.

The accidents identified are summarized 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).

Based on the LWD obtained from the labor office accident statistics, the severity level of construction accidents is categorized as minor, moderate, serious, severe, critical, and fatal [10]. The categorization based on LWD 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 immediate or after several LWD

The number of accidents in each category is given in Table 2. Most accidents were of moderate severity level (36.3%). The number of accidents, frequency of occurrence (%), and severity level of each type of accident are shown in Table 3. Out of 226 accident cases analyzed, falling from height (FH) was most frequent (43%). The average LWD was approximately 41 days between the years 2008 and 2013. The percentage of occurrence of accidents within each severity level based on experience is given in Table 4. The type and location of injuries are presented in Tables 5 and 6, respectively. New and experienced workers are categorized according to their years of experience. Those with more than three years of working experience were considered to be "experienced".

Table 2. 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 3. 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

Table 4. 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
New (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 5. Type of injuries within severity level.

Types of Injury (%)	Percentage of Accidents within Severity Level					
	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 6. Type of injured body location within severity level.

Injured Bodily Location (%)	Percentage of Accidents within Severity Level					
	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

4.2. Preparation of Checklists

For accidents occurring in the construction industry, necessary safety measures are determined by considering the North Cyprus OSH rules and regulations. Every safety item is then weighted according to the possible type of accident/injury, followed by calculating SC. In order to determine this, an SC checklist was established [46], and an AP was determined by revising the existing work. The checklist (Appendix A) consists of four parts: Part A is warning signs and instructions; Part B is loading, incorrect handling, and related measures; Part C is ergonomics and physical hazards; and Part D is environmental factors. Yes or no type questions were developed to determine the availability of warning signs and instructions (part A) and the environmental factors (part D). Other risk factors were assessed using a 5-point Likert scale.

The weight for each part of the SC checklist was determined by the AHP. The first step of AHP is to compute the vector of criteria weights, as is seen in Table 7. The second step is to compute a matrix of option scores, and the third step is an expert ranking of the options. After three iterations, the weights for parts A, B, C, and D were obtained (0.04, 0.62, 0.24, and 0.10, respectively). These weights are the eigenvector of relative importance. In each part, every question is weighted equally. After the data were collected from the four construction sites, weighted scores of each part were calculated. In this study the consistency index (CI) is 0.185.

Table 7. 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

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 [47]. Based on the analysis, a Boolean (yes or no) type checklist was administered for each type of accident (Appendix B). After the data were collected from the construction sites, weighted scores and AP were calculated. In this case, 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.

4.3. Work Trades

Work trade involves listing all the work tasks and related injuries from accident investigation reports. Appropriate safety barriers and appropriate personal protective equipment were determined for each type of accident, and a Boolean (yes or no) type checklist was used to measure the presence of safety barriers. These checklists were completed through visits to different construction sites and assigning 0 and 1. After the analysis, weighted scores for each type of accident were calculated. Firstly, work tasks were determined for the specific job. After that, according to the past accident investigation reports, the accident types and injured body parts were categorized, and possible preventive measures were suggested. After that, the weighted scores were calculated.

4.4. Application of Fuzzy Operator

In this study, according to the estimated risk value, linguistic expressions are used to determine the SC, SB, AP, S, and RL. The fuzzy OR max operator is used to determine the effectiveness of each variable (SC, SE, AP and SB), and the Fuzzy AND min operator is used for the final risk level estimation. The linguistic variables used are presented in Table 8 where expert opinions determine linguistic variables.

Table 8. Linguistic expression of variables and risk level.

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

4.5. Using MATLAB Program

The fuzzy function of the MATLAB program is used to determine the defuzzification value of the risk level. In order to define fuzzy rules, different possibilities are considered for each input, and 625 fuzzy rules are defined for the model. There are four inputs in the model: SC, S, AP and SB. There is one output which is RL. RL is estimated faster by using this program.

4.6. Application of FRAM

4.6.1. Choosing the Sample of Workers to Interview

Four small-sized construction industries in North Cyprus were examined in this study. Three of the construction sites were located in the city of Girne and one in Lefkoşa. The Girne sites included the construction of (1) a second floor and building maintenance, (2) a hospital, and (3) residences (apartments, townhouses, and villas). The site in Lefkoşa was the construction of a business center. These four sites were evaluated collectively to determine the accident risk level of the construction industry in North Cyprus.

4.6.2. Identification of Safety Climate Factors

The aggregate current safety level in the construction sites was calculated to be 45.43%, which is "average" based on the fuzzy rules (Table 8).

4.6.3. Identification of the Possibility of Occurrence of Different Accident Modes

Weighted scores of each type of accident obtained from the checklists are presented in Table 9. 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 9. 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

4.6.4. Estimation of Expected Severity for Each Accident Mode

The highest severity is associated with FH (53.83%), as shown in Table 10. The severity level for FH is "average" and "very low" for other types of accidents.

Table 10. Severity for each type of accident.

Modes of Accident	LWD Index (F)	Occurrence Frequency Index (S)	F × S	%
Falls (F)	0.04	0.07	0.00	7.15
Falling from height (FH)	0.04	0.49	0.02	53.83
Falling from vehicle (FV)	0.03	0.02	0.00	2.09
Struck by moving vehicle, including heavy equipment (SMV)	0.04	0.16	0.01	15.21
Compressed by equipment or objects (C)	0.03	0.07	0.00	4.74
Contact with machinery and moving parts (CM)	0.02	0.11	0.00	6.81
Traffic accidents (TA)	0.05	0.05	0.00	7.30
Contact with electricity (CE)	0.05	0.02	0.00	2.88

4.6.5. Estimation of Safety Barriers

Safety barriers obtained for the eight accident modes are presented in Table 11. The safety barrier for F and CE was "average," low for FH, S, C, CM, and TA, and very low for FV.

Table 11. 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

4.6.6. Final Evaluation of Risk Level by Using FRAM

The minimum risk level for each accident mode evaluated by using FRAM is shown in Table 12. For all parameters and risk levels, numerical values are described using linguistic variables, and fuzzy rules are defined for each case. The risk level for FH is low and very low for other types of accidents. Although the risk level is low, this does not negate 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 13. Risk levels for each accident mode obtained by these two approaches are similar but not the same, as shown in Table 13.

Table 12. 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	7.15	42.85	45.43	45.00	7.15
FH	53.83	42.85	45.43	37.50	37.50
FV	2.09	31.25	45.43	8.30	2.09
SMV	15.21	31.25	45.43	22.90	15.21
C	4.74	50.00	45.43	22.90	4.74
CM	6.81	23.33	45.43	37.50	6.81
TA	7.30	23.33	45.43	37.50	7.30
CE	2.88	28.57	45.43	40.00	2.88

Table 13. 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

5. Results and Discussion

This study highlights the risk level at construction sites in North Cyprus using a modified risk assessment model that employs linguistic variables. There are two types of risk assessment models, traditional and fuzzy models. The developed FRAM is an efficient tool to identify and determine the existing risk levels for accident modes and work trades. Moreover, safety barriers show the necessary improvements for the current situation in construction sites. Therefore, FRAM can be applied to the existing and future data to determine risk levels for the construction industry and improve the safety measures on a construction site. The checklist was prepared by considering the rules and regulations and accident statistics of the North Cyprus construction industry and improved and modified by using reference models. In addition to these, the weights of checklists were determined through an AHP. Linguistic variables were used to assess risk levels by considering the fuzzy relationships. A MATLAB program was crucial in determining the risk levels by using the inputs of variables of the model and the rules, which are the relationship between the variables mentioned. Fuzzy rules were defined by the fuzzy OR operator, and the risk level was calculated by the fuzzy AND operator. The defuzzification function was the centroid. The difference between previous studies summarized above and FRAM is that FRAM uses historical and fuzzy approaches to calculate the risk levels. The MATLAB program calculates site-specific defuzzification values in a short time.

Using FRAM, we calculated the risk level for the construction industry in North Cyprus and highlighted the need for appropriate reduction measures. When applying the modified model, FRAM, 625 rules were defined to the MATLAB software package to assess the risk level for each type of accident. This model uses the Fuzzy set theory to deal with the uncertainty, and linguistic variables were used to define the risk level in the construction sites.

FRAM and FRAM MATLAB programs use fuzzy operators to determine a final estimation of RL of accident types from four variables, SC, S, AP, and SB. FRAM, in this study, differs from other methods in that weighed scores are calculated for each parameter. In addition, FRAM uses AHP to calculate the weight of the checklists to determine the final values. In addition, FRAM uses historical values to determine the severity of accidents at the site. There are distinct advantages of using FRAM; it is not complicated and is an effective model that can be applied easily in small-sized construction industries. The comparison of the FRAM results with its MATLAB results are presented in Table 14.

Table 14. 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 rules and regulations were used to prepare a checklist for determining the first variable, named safety climate. 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%, sites 3 and 4 are 14.29%, as shown in Tables 15–18). Therefore, the risk of an accident is very high, and the safety climate on-site should be improved.

Table 15. Results for each 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 16. Results for each 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 17. Results for each 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 18. Results for each 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 for the types of accidents for each site are as follows: at site 1; F and FH is very high, FV, S, and CE are high, CM and TA are average, and C is low. At site 2, C is average, F, FH, FV, and S are low, and it is shallow for other types of accidents. At site 3, C is average, and it is very low for other types of accidents. At site 4, C is average, F, FH, CM and TA are inadequate, other types of the possibility of accident occurrence is very low. As a result, 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 inadequate, and severity is high. The sites' values are presented in Tables 15–18.

The expected severity for each type of accident is measured through Equation (2), and the results are presented in Table 9. The severity level for FH (S = 53.83%) is average, which means that FH has the highest LWD and the highest occurrence of the types of accidents. The severity level is low for other modes of accidents, with less than 20% of the weighted score, as seen in Table 9.

Stages of the general construction site are listed, and the type of accident that can take place is determined for each step. The safety barriers needed to reduce the possibility of an accident are determined according to the accident modes. Safety barriers at site 1 for each type of accident are as follows: at site 1, FV and CE are high and low for S, C, CM and TA and very low for F and FH. Safety barrier for FV is very high at site 2. At site 3, F, FH, FV is very high. At sites 4, F and FV are very high. Moreover, at sites 2, 3 and 4, safety barriers were calculated as high for the remaining accident modes. The results show that the safety barrier level changes from one site to another, which can be explained by the lack of enforcement of rules and regulations and inadequate control mechanisms.

According to the results in general, the safety climate is very low. Safety barriers are inadequate and need to be improved. Safety barriers are particularly low for F and FH, which explains why the probability of these accident modes is high. The severity of FH is high and low for other modes of accidents. The possibilities of the occurrence of each type of accident change from very high to average, as seen in Table 8.

According to the results of FRAM, the risk level at site 1 for FH is average and very low for other types of mechanisms of accidents. At sites 2, 3, and 4, the risk level is low for all types f accident modes. The risk level is low for almost all types of accidents since the formula necessitates the minimum of all variables to be taken to obtain minimum risk at each site.

6. Conclusions

The major implication of our research is that a more easily implemented risk assessment model using linguistic variables can be utilized to accurately identify risks for different work tasks in the construction industry. The modified fuzzy risk assessment model we developed performs just as well as other models.

This model can be used to assess risk at different stages of construction and for different work tasks. On any given day, the on-site engineer, OSH professional, or any employee with OSH background can enter linguistic variables into the model that describe the working conditions and then run the program to get the risk level. Once the risk level and areas in need of improvement are identified, preventive measures can be taken. Due to the dynamic nature of working conditions at construction sites, and varying work tasks, this model brings an advantage over other models as a tool for quick decision making.

Future research can focus on including worker characteristics in the model to measure the impact on risk. These characteristics may include education level, work experience, work hours, time of work activity, construction project size and location [5,34], as well as occupation, gender, age, nationality and language [17,48,49]. These factors may increase or decrease safety behavior. Such parameters will bring more power to the model in identifying current risks. This model will contribute to establishing a sustainable risk management system for small sized construction industries.

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Appendix A

Preparing checklist to determine current safety level [46].

Table A1. 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 A2. 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 (PPE) (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 A3. 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 A4. 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 $\leq$ 80 decibels)		
4. Illumination		
5. Ventilation/Dust		
6. Lighting		
7. Vibration		

Appendix B

Preparing checklist to estimate the possibility of occurrence of accidents.

Table A5. Checklists for possibility of occurrence of accident modes [36].

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?		

Table A5. *Cont.*

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?		

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