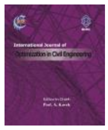
INTERNATIONAL JOURNAL OF OPTIMIZATION IN CIVIL ENGINEERING
Int. J. Optim. Civil Eng., 2018; 8(3):433-452



A FLEXIBLE METHOD OF BUILDING CONSTRUCTION SAFETY RISK ASSESSMENT AND INVESTIGATING FINANCIAL ASPECTS OF SAFETY PROGRAM

R. Ghousi[1*, †], M. Khanzadi[2] and K. Mohammadi Atashgah[3]
[1]*School of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran*
[2]*School of Civil Engineering, Iran University of Science and Technology, Tehran, Iran*
[3]*Department of Civil Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran*

ABSTRACT

Construction industry has the highest ratio of fatality of workers in comparison with other industries. Construction safety has been always a matter of focus to control safety risks. This article presents a new flexible method of safety risk assessment by adding Hybrid Value Number (HVN) to the assessment equation. As a result of using this method, the results of assessment process will be more consistent with the project's conditions, as well as being more trustful. It could provide a better perspective of safety risks for project managers. The most significant outcomes of this research are as follows: 1) the most influential factors which affect safety risks in building construction projects are "the proficiency and the experience of workers", "the complexity of construction technology" and "time limitation", 2) the biggest risk priority numbers belong to "Struck by falling objects" and "Falling to lower levels" hazards, 3)a necessary safety program must contain Personal Protective Equipment (PPE), safety measures and safety training, 4)Project managers can decrease 75% of total safety risks by investing less than 1.5% of construction budget on safety programs.

Keywords: safety; risk assessment; hybrid value number; safety cost; safety program; building construction.

Received: 10 September 2017; Accepted: 14 November 2017

1. INTRODUCTION

Building projects has always been faced with many problems in terms of time and cost

---

[*]Corresponding author: School of Industrial Engineering, Iran University of Science & Technology, Tehran, Iran
Ghousi@iust.ac.ir (R. Ghousi)

during construction. Lots of factors can impact on problems such as political situation, inflation and construction accidents. These problems which affect all aspects of projects' success are known as Project Risks. Many project managers consider safety risks as the most important ones, considering their striking consequences [1]. Construction industry contains 5% of all industries' workers, but 14% of work accident fatalities happen in this industry [2]. Many researchers have focused on construction safety in recent years. Zhou's investigation [3] indicates that the number of articles in this field has increased six times between 2000 and 2011. This trend shows the importance of safety issues in construction projects. On the one hand, working accidents put financial pressure on projects. On the other hand, they impact on workers' quality of life as well as their families due to the risk of injury and fatality. Project Managers pay attention to safety issues because of direct and indirect cost of accidents [4]. However, many sociologists believe that social side-effects of work accidents are more significant than financial ones [5].

This paper provides the results of the research conducted by authors, looking for a range of useful results for construction managers and researchers in safety field. Authors present a new method for safety risk assessment which makes more consistency of results in project conditions. Moreover, an investigation on safety cost clarifies how a safety program can affect the safety risks for managers and help them make decisions about defining a safety program and reimbursing it.

2. LITRETURE

The description of "safety" is far from an absolute. It depends on the limitation of acceptable hazards. The main factors that define the limitation of acceptance are time and environmental situation. If the probability and intensity of an accident's occurrence are below the acceptable limit, the surveyed environment, work, and device are safe [6]. Making a safe workplace needs managing safety risks. Planning, identification, assessment, measurement, and control are five steps upon which safety management is based [1]. In the field of construction, the majority of safety researches are related to building projects [3] and most of them pay attention to the process of Risk Assessment [5]. The output of risk assessment prioritizes the identified risks, and shows the critical level of each one. A long period of research in this field indicates that researchers have tried to assess risks by considering single or multi factors. The authors divide these factors into four groups.

The first research group uses just one factor to evaluate risks. Cheng [7] used frequency factor for this issue. The results of his survey showed that 39% of work accidents are related to those workers who have less than one month experience. Moreover, 12% of such incidents occur on the first day of work. Memarian [8] who studied masonry activities, based his research on frequency and consequence level separately. He found out that critical frequency and consequence are different for masons and labor who work in masonry activities. Dewlaney [9] focused on green building construction, and found out that people working in this projects are 24% more likely to have the accidents related to falls from height because of the specific features of such projects.

The second group of articles was based on two factors in assessment process. Usually, these two factors are frequency and impact level of incidents. Sun [10] tried to prioritize the existing risks of construction phase in Bajing Olympic Venus. He defined five levels of probability, and five levels of impact to compare risks with each other. The product of these factors made the final priority number of each risk. Fung [11] used the same method for showing the risk level of each main work item which workers face with. The outcome showed that one of the hazardous jobs of construction projects is supervising the project place.

The third group adds exposure factor to the assessment trend. They tried to increase the accuracy of results through using three factors. Hallowell [12] used the product of three factors to define the most critical risks of construction projects. Kim [13] used labor input factor as the third one. He tried to add the effect of 'number of activities' on workers to the result of risk assessment. He showed that roof works have the highest safety risk in comparison with other tasks. Gurcanli [14] initially used Work Breakdown Structure (WBS) to identify the whole activities of building construction process. WBS and Triple Factor Method helped him increase the accuracy level of results. Finally, he used these results in safety cost investigation.

The fourth group tried to use more than three factors in the assessment phase. One of the most functional methods in this group has been devised by Al-Anbari [15] who mixed both health and safety issues. He described four levels of evaluated risk and defined an appropriate measure for each situation.

In terms of safety cost, two groups of surveys have been conducted. The initial one concerns the lack of Safety Management Cost. In other words, it relates to the cost of work accidents. Direct Cost and Indirect Cost are two subsets of Accident Cost. Direct Cost is more feasible than the Indirect Cost. However, the majority of accident costs are related to the indirect part. The relation between Direct and Indirect Costs is similar to the appeared and the hidden parts of an iceberg [16]. Pellicer [17] investigated the costs of construction accidents in Spain and found out that a large amount of those costs are spent on the accidents related to "fall from height". Furthermore, Sousa [18] presented a new method for predicting the Direct Cost of accidents by considering the amount of their risks.

The other group of researchers has analyzed those safety management costs which are related to safety program and accident preventing costs. Ikpe [19] investigated two sets of costs and benefits. To do so, he put direct and indirect costs on one side and direct and indirect benefits on the other side. Comparing the result of such costs and benefits can show the financial justification of a safety program. To show the appropriate proportion of safety cost as well as finding the optimum amount of it, Hallowell [20] used the optimum safety cost diagram. He analyzed 13 safety programs in order to show which one will have the most desired outcome for the project managers. Lopez-Alonso [21] analyzed the rate of safety cost and that of accidents in every phase of building projects. Results showed that 54% of accidents occur during the period of building structures, but it consumes 32% of safety cost. Questionnaires indicated that 20% of safety cost is unknown for contractors during the evaluation phase. Thus, they will realize this difference in the operation phase [22]. The most functional probe into safety cost field belongs to Gurcanli [14] who presented a diagram to predict safety cost. This diagram helps project managers and contractors estimate safety cost through considering construction area.

Construction projects are unique and they have specific features that make them distinct from each other. The lack of a flexible risk assessment method which can make the results compatible with a project's conditions is obvious. Furthermore, only a few articles have paid attention to the effect of safety costs on safety risks. Because of such reasons, the authors have focused on the mentioned research gapes in their research.

3. METHODOLOGY

This section shows the methods and the tools which were used by the authors to achieve the results in the current research. Fig. 1 indicates a graphical representation of the methodology. Authors conducted this research through 27 interviews. Initially, a group of construction and safety experts were selected as an expert team. The experiences and the knowledge of the expert team were used as a database. Moreover, their opinions formed the basis of all research steps.

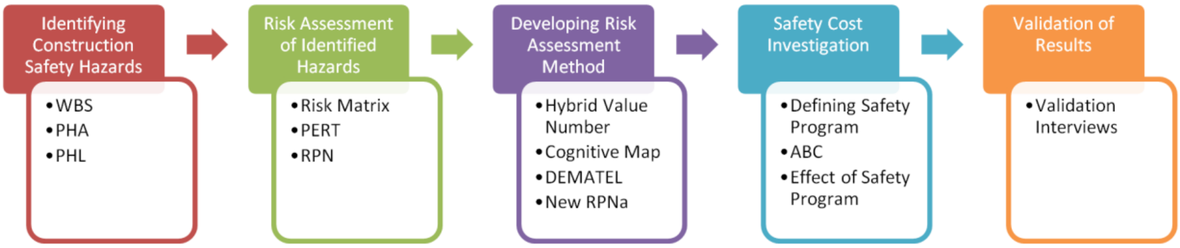


Figure 1. Graphical representation of the methodology

3.1 Identifying safety hazards in construction

In order to identify hazards in construction, we need to determine which work items and catastrophic events are the most common. According to the literature studies, the initial list of main risks in the building construction was prepared. Then some interviews and discussions with the expert team were conducted. The results of the interviews were mentioned in Fig. 2.The tangible difference of this list with the previous researches is considering "Sudden Collapse of Underground Cavities or Pits".

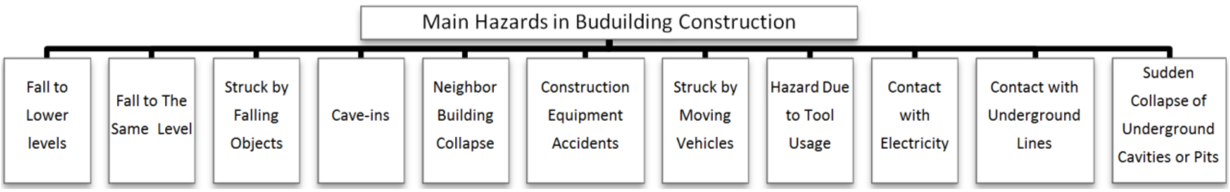


Figure 2. Final list of main hazards in building construction

3.1.1 Work breakdown structure

To determine occurrences of each stage of construction in Fig.2, Work Breakdown Structure (WBS) was carried out and various stages of construction were defined afterwards. If WBS is broken down into more levels, more details will be revealed and consequently the process of hazard identification will become more complicated [23]. As a result, one level of WBS was conducted which is specified in Fig. 3.

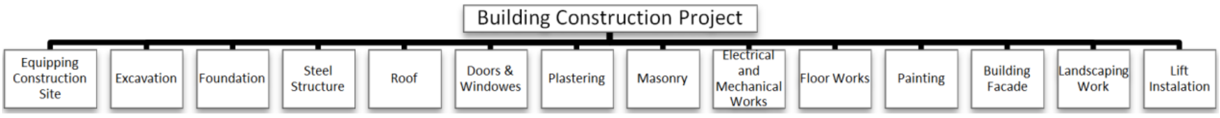


Figure 3. Work breakdown structure for main work items

3.1.2 Preliminary hazard analysis

Preliminary Hazard Analysis (PHA) was produced for safety of United States' military industry in early 50s [24]. The results of this analysis have led to Preliminary Hazard List (PHL) that shows detected risks. In this study, based on the interviews with the expert team, Table 1 was created as a PHL. The table has determined which work items contain which hazards. Moreover, these risks are determined by assigning a specific code.

Table 1: Preliminary Hazard List of Building Construction

Hazard/Work item	Equipping Construction Site	Excavation	Foundation	Steel Structure	Roof	Doors &Windows	Plastering	Masonry	Electrical and Mechanical Works	Floor Works	Painting	Building Facade	Landscaping Work	Lift Installation
Fall to Lower Levels		B1	C1	D1	E1	F1		H1				L1		N1
Fall to The Same Level							G2		I2		K2			
Struck by Falling Objects				D3	E3	F3		H3				L3		
Cave-ins		B4	C4											
Neighbor Building Collapse		B5	C5											
Construction Equipment Accidents	A6	B6	C6	D6										
Struck by Moving Vehicles	A7	B7	C7	D7									M7	
Hazard Due to Tool Usage	A8			D8	E8	F8	G8		I8	J8	K8	L8	M8	N8
Contact with Electricity	A9			D9					I9					N9
Contact with Underground Lines		B10												
Sudden Collapse of Underground Cavities or Pits		B11												

3.2 Risk assessment of identified hazards

The next step is evaluating the identified risks. The initial assessment is based on two criteria: severity and probability of occurrence. If a hazard takes critical values in both parameters, it will be a critical risk. Otherwise it will be considered as a non-critical priority.

3.2.1 Risk matrix

Before assessment, the criteria and basis for each parameter should be determined. Two tables were designed to score each factor, indicating the differences between levels of each one. Table 2 shows the levels of probability and the score that belongs to each level. To make the severity table, Hallowell's article [12] was used as a basis. He determined non-linear levels due to the significant difference between the levels of severity. According to the expert team and Hallowell [12], Table 3 was introduced as the basis of severity.

Table 2: Score of probability levels

Probability	Score
Impossible	1
Rare	2
	3
Occasional	4
	5
Probable	6
	7
Frequent	8
	9
Very frequent	10

Table 3: Score of Severity Levels

Severity	Score
Discomfort	1
Pain	4
First Aid	9
Medical Case	16
Significant Medical Case	25
Short Lost Work Time	36
Long Lost Work Time	49
Minor Disablement	64
Major Disablement	81
Fatality	100

3.2.2 Project evaluation and review technique (pert)

Nor every type of risk necessarily has an exclusive output. Depending on various factors, it can be heavier or lighter than the predicted outcome. Project Evaluation and Review Technique (PERT) method is used to solve this problem. PERT method was devised for project scheduling based on the probable time of activities in which three modes of time are used: pessimistic, likely and optimistic [23]. The average value is obtained according to Eq. 1. As a result of considering optimistic and pessimistic modes, using PERT method to determine the severity of the accident can be closer to reality.

$$t_e = \frac{t_0 + 4t_m + t_p}{6} \quad (1)$$

3.2.3 Risk priority numbers

Primary Prioritizing has been devised based on severity and probability. This process has also been used in previous studies by Sun [10] and Fung [11] to assess the safety risks in construction. Equation 2 shows the process of initial risk assessment. Here a greater Risk Priority Number (RPN) represents more critical risk and higher priority for safety action.

$$RPN = (Severity) \times (Probability) \qquad (2)$$

3.3 Developing risk assessment method

Efforts have been made in previous studies to increase the accuracy of assessment; several factors have been added to Eq. 2 for this purpose. As a case, Kim used "labor Input" factor as the third factor [13]. Gurcanli and Hallowell added "Exposure" factor to assessment equation [12] [14]. It is obvious that such risk assessments are neither flexible with various construction types nor compatible with different construction conditions. Hence the authors of this paper have provided a new assessment method that can adapt itself with every construction conditions by considering the factors influencing the safety risks. This flexibility is derived from a new risk assessment parameter called Hybrid Value Number (HVN).

3.3.1 Hybrid value number (HVN)

HVN may contain many subsets. The product of multiplying each factor in its weight makes the value of this factor. Equation 3 shows the structure of HVN. In this equation, F_i is the factor which influences risk, while W_i is the weight of each factor. Defining the factors which are related to the project situation, and the managerial team or the project experts can determine those factors. Obviously, such factors can change depending on the project situation, and their quality and quantity should be defined based on the project’s type and situation. Features of this parameter make specific abilities which can be used in various projects and situations. Flexibility and adaptation of HVN make it convenient for all kinds of project risk assessment.

$$HVN = \sum_{i=1}^{n} W_i F_i \qquad (3)$$

3.3.1.1 Factors influencing construction safety risks

As a result of the interviews with the expert team, "Proficiency and Experience of Workers", "Complexity of Construction Technology" and "Time Limitation" are recognized as the most significant factors influencing construction safety risks. According to Cheng [7], 39% of construction accidents happen to workers who have less than one month experience. It shows the importance of proficiency and experience factor. Dewlaney and Fortunato [9][25] mentioned that green buildings were 9% more likely to have work accidents duo to their complexity of construction. Thus, the complexity of construction technology can affect the safety level of project. On the other hand, time limitation puts pressure on managers and workers of construction projects alike, hastening them over the course of projects. This, in turn, can reduce the safety level of project. Considering these factors, the output of risk assessment can be unique and completely adaptable with the project conditions through scoring each factor in accordance with its relevant situation.

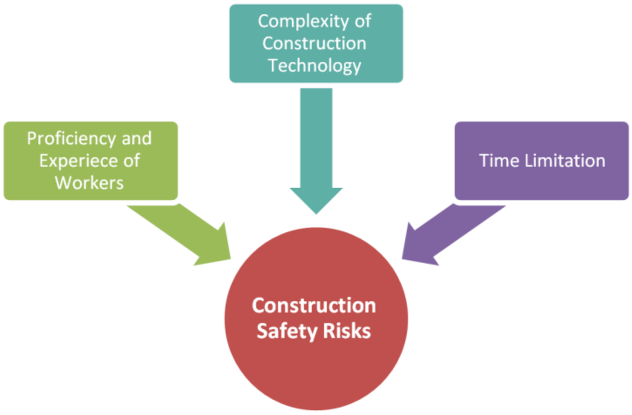


Figure 4. Factors affecting construction safety risks

3.3.1.2 Cognitive map

In order to define the weight of each factor of HVN, initially, the interaction among them should be defined. One of the most frequent ways to show the interactions among factors is drawing a cognitive map. Cognitive map is a graph that contains two groups of elements. One group includes nodes that indicate the factors in decision making or assessment process while the second group consists of the arrows; each arrow indicates the relationship between two nodes [26]. The whole nodes and arrows provide a cognitive map. Fig. 5 demonstrates the cognitive map of factors affecting construction safety risks.

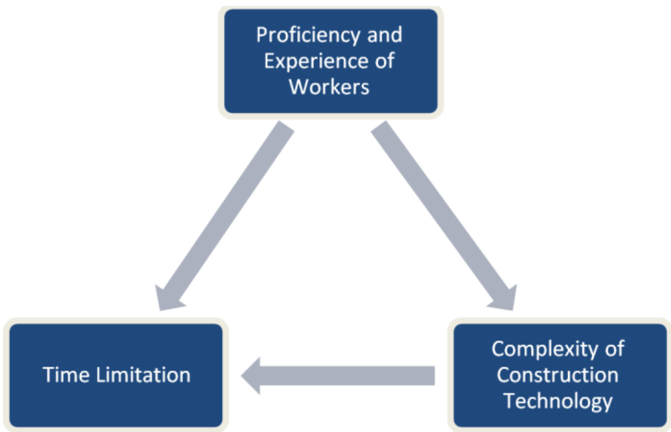


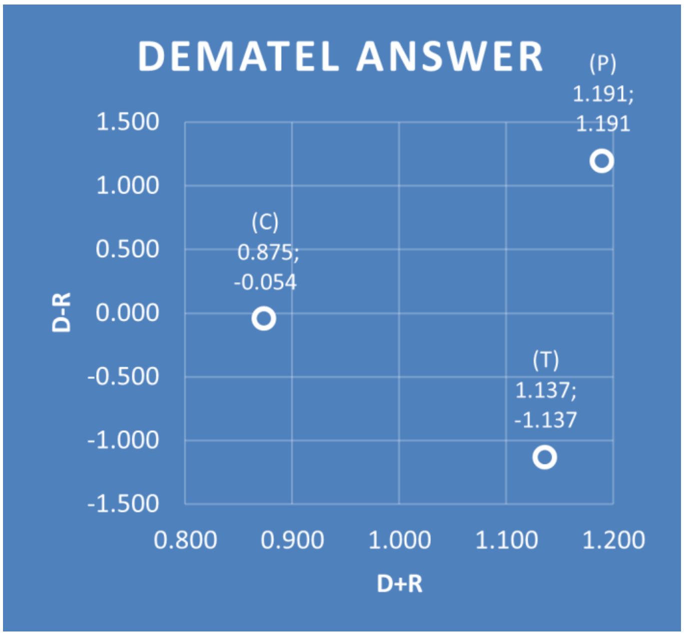
Figure 5. Cognitive map of HVN factors

3.3.1.3 Decision-making and trial evaluation laboratory (Dematel)

Every arrows of the cognitive map were scored by the expert team based on Table 4 which is commonly used in DEMATEL technique. By using these scores as an input, DEMATEL simplifies the interaction among factors. The output shows the influence of factors between each other. In other words, the output indicates that how much each factor is affected by the other factors and similarly how much it affects the other ones [27]. Finally, based upon the output of DEMATEL which is demonstrated in Fig. 6, the weight of each factor was determined. Hence the weight of proficiency and workers' experience factor equals 0.3716, the weight of complexity of construction technology factor equals 0.2732, and the weight of time limitation factor equals 0.3716. [W_P=0.3716, W_C=0.2732, W_T=0.3552]

Table 4: Arrows of Cognitive Map Scoring Base

effect	Score
No effect	0
Low	1
Moderate	2
High	3
Very high	4



Note: P: Proficiency and experience of workers, C: Complexity of construction technology, T: Time limitation

Figure 6. Dematel answer

3.3.2 New RPNS

The initial equation of risk assessment contains solely probability and severity of occurrence. By adding HVN to this equation, the final equation comes as follows:

$$RPN = P \times S \times HVN \tag{4}$$

$$\rightarrow RPN = P \times S \times [(W_P \times F_P) + (W_C \times F_C) + (W_T \times F_T)] \tag{5}$$

$$\rightarrow RPN = P \times S \times [(0.3716 \times F_P) + (0.2732 \times F_C) + (0.3552 \times F_T)] \tag{6}$$

HVN in risk assessment can open up the possibility of using this equation in all fields of construction and even in other industries since the quantity and quality of factors as well as their weights, are completely flexible and changeable depending on the conditions. New priority of hazards can be created by using Eq. 6 as a basis of risk assessment and due to HVN parameter; it will have higher accuracy in comparison with the initial version.

In order to score factor values related to project conditions, tables number 5, 6 and 7 have been provided as a result of the expert team's opinion. Table 5 contains 2 parts; the total amount of both parts will make the final score of proficiency and workers' experience factor. Choosing the appropriate score in each phase of project depends on the average of all the workers' score in that work item. Thus project managers or other responsible people in a project may take part in risk prioritizing process by using these tables.

Table 5: Value of 'proficiency' and 'workers' experience' factor based on project situation

Proficiency of Workers	Score		Relevant Experience of Workers	Score
			More than 4 years	0
Fully trained	1		Between 2 to 4 years	1
High trained	2	+	Between 1 to 2 years	2
Moderate trained	3		Between 6 to 12 months	3
Low trained	4		Between 3 to 6 months	4
Without training	5		Less than 3 months	5

Table 6: Value of 'complexity of construction technology' factor based on project situation

Complexity of technology	Score
Very simple	1 2
Simple	3 4
Moderate	5 6
Complex	7 8
Very complex	9 10

Table 7: Value of 'time limitation' factor based on project situation

Time limitation	Score
Normal	1
95% of normal	2
90% of normal	3
85% of normal	4
80% of normal	5
75% of normal	6
70% of normal	7
65% of normal	8
60% of normal	9
55% of normal and less	10

3.4 Safety cost investigation

Investing in safety can reduce the cost of accidents of project operation [20]. Safety Costs are influenced by the type of safety program which is chosen by the project authorities. Before investigating in safety cost a necessary and relevant safety program should be defined.

3.4.1 Defining safety program

As a result of the interview with the expert team, a fundamental and necessary safety program is defined as the basic program for all building construction projects. The result of interviews indicates that a successful safety program must have three parts: "Personal Protective Equipment (PPE)", "Safety Measures" and "Safety Training". These are three essential parts of safety program that have been shown in Fig. 7. To define the details of safety program, Gurcanli's research [14] was used as a basis of interviews. Table 8 is the final outcome of those interviews, showing necessary PPEs and Safety Measures for each main work item. In terms of safety training, 2 hours of specific safety training concerning each main work item must be provided for every worker who participates in the operation process of that item.

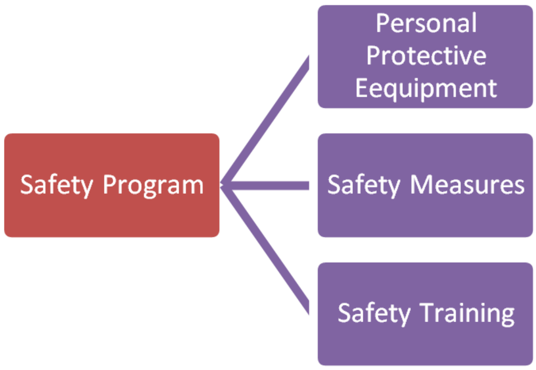


Figure 7. Safety program's essential parts

Table 8: Necessary PPEs and safety measures for each hazard

Hazard	PPE	Safety measure
Fall to lower levels	Helmet, Safety harness	Side guards, Warning signs and safety tapes, Safety nets
Fall to the Same Level	Helmet	
Struck by Falling Objects	Helmet	Fences, Warning signs and safety tapes
Cave-ins	Helmet	Warning signs and safety tapes, Retaining structures, Two-way radio
Neighbor Building Collapse	Helmet	Retaining structures, Two-way radio
Construction Equipment Accidents	Helmet	Warning signs and safety tapes, Two-way radio
Struck by Moving Vehicles	Helmet, Reflective work vests	Warning signs and safety tapes, Two-way radio
Hazard Due to Tool Usage	Helmet, Goggle, Gloves, Protective footwear	Safety switch
Contact with Electricity	Helmet, Gloves, Protective	Safety switch

	footwear	
Contact with Underground Lines	Helmet	Warning signs and safety tapes, Two-way radio
Sudden Collapse of Underground Cavities or Pits	Helmet	Warning signs and safety tapes, Two-way radio

Note: First Aid Tool Box and Fire Protection Tools are necessary for all work items

3.4.2 Activity based costing

Activity based costing (ABC) is a new method that provides a more accurate costing based on details [14]. ABC can be helpful in safety cost estimation due to numerous details of safety program. By combining Table 1 and Table 8, one can clearly find out which main work item needs which part of safety program based on its hazards. Table 9 shows the final details of safety program; hence it could be the foundation of estimating safety cost. PPEs and safety training cost estimation in each work item are defined based on the number of workers in that item. Safety measures cost estimation which relates to the conditions and the features of the project is defined, too. The total sum of all safety program's subsets is the total cost of safety program in each item.

Table 9: Details of safety program for each main work items

Work item	PPE					Safety measures								
	Helmet	Goggle	Gloves	Protective Footwear	Safety Harness	Reflective Work Vests	Side Guards	Warning Signs and Safety Tapes	Safety Nets	Fences	Safety Switch	Two-way Radio	Retaining Structures	Safety Training
Equipping Construction Site	●	●	●	●		●		●			●	●		●
Excavation	●					●	●	●				●	●	●
Foundation	●					●	●	●				●	●	●
Steel Structure	●	●	●	●	●	●	●	●	●	●	●	●		●
Roof	●	●	●	●	●		●	●	●	●	●			●
Doors &Windows	●	●	●	●	●		●	●	●	●	●			●
Plastering	●	●	●	●							●			●
Masonry	●		●		●		●	●	●	●				●
Electrical and Mechanical Works	●	●	●	●							●			●
Floor Works	●	●	●	●							●			●
Painting	●	●	●	●							●			●
Building Façade	●	●	●	●	●			●		●	●			●
Landscaping Work	●	●	●	●		●		●			●	●		●
Lift Installation	●	●	●	●	●		●	●	●		●			●

3.4.3 Effect of safety program on safety risks

In terms of efficiency of safety program, the interviews with the expert team indicate the amount of risk reduction as a result of dealing with risks through safety program. Furthermore, it shows how much of safety risk for each hazard can be decreased.

4. RESULTS AND DISCUSSION

4.1 Risk results

A commercial building project was selected as a case study to do the rest of survey. The investigation of safety cost needs such a case in order to make the results more tangible. Initially, risk assessment was conducted based on two parameters: probability of occurrence and severity of incident. The results of this assessment (Eq. 2) are shown in Table 10. In this kind of prioritizing, the project’s conditions are not considered; consequently, the results will be generalized to all construction projects. The most critical hazards, which are based on general risk assessment, are as follows:

- “Struck by Falling Objects” hazard in Steel structure item operation
- “Struck by Falling Objects” hazard in Building façade item operation
- “Fall to Lower Levels” hazard in Building façade item operation
- “Fall to Lower Levels” hazard in Steel structure item operation
- “Fall to Lower Levels” hazard in Lift installation item

Table 10: Risk priority of each hazard

Priority	P×S	P×S×HVN	Priority	P×S	P×S×HVN
1	D3	D3	24	A6	E8
2	L3	D1	25	I8	H3
3	L1	N1	26	D9	H1
4	D1	L3	27	C7	F3
5	N1	L1	28	D7	I8
6	E1	D8	29	A9	F1
7	F8	E1	30	C4	B10
8	D8	N8	31	B5	C7
9	A7	D6	32	B1	A6
10	M7	B4	33	C1	C4
11	D6	B6	34	N9	C1
12	F3	B7	35	M8	M8
13	A8	E3	36	C6	I9
14	N8	L8	37	I9	A9
15	E3	M7	38	G8	C6
16	F1	D9	39	K8	K8
17	B4	D7	40	J8	G8
18	L8	N9	41	B10	B11
19	B6	F8	42	C5	C5
20	B7	A7	43	G2	J8
21	H3	B5	44	B11	I2
22	E8	B1	45	I2	G2
23	H1	A8	46	K2	K2

The most significant hazards relate to “Struck by Falling Objects” and “Fall to Lower Levels” which are also recognized by previous researchers as the most critical hazards or leading causes of death in construction industry [12][14][18]. In terms of adapting and specifying the results based on project situation, HVN is added to the assessment equation as the third parameter (Eq. 6). The new results of assessment are shown in Table 10. Compared to the initial assessment, some hazards become more critical and others become less by applying HVN. Table 11 indicates the changes in new results in comparison with previous ones, demonstrating the influence of project conditions on identified safety risks. It also shows how HVN can change risk priorities. In fact, these changes help managers face risks more appropriately; the more risks are recognized, the better they can be dealt with.

Table 11: HVN effect on risk priority of hazards

HVN criticality rank	Main work item	HVN effect on risk priority
1	Lift Installation	↑
2	Steel Structure	↑
3	Excavation	↑
4	Roof	↑
5	Building Façade	↑
6	Electrical and Mechanical Works	–
7	Masonry	–
8	Painting	–
9	Landscaping Work	–
10	Foundation	↓
11	Plastering	↓
12	Equipping Construction Site	↓
13	Doors &Windows	↓
14	Floor Works	↓

Finally, Fig. 8 shows the entire safety risk of each main work item. It indicates that three work items are the most critical ones: "Steel Structure", "Excavation" and "Building Façade" which constitute about 50% of the whole safety risk during construction phase. Another crucial point is that among the14 defined main work items, 7 of them make up 78% of the entire safety risk, while the other 7 items account for just 22% of those risks. Such information can help project managers realize which stage of construction needs more attention and more investment toward controlling safety risks.

4.2. Safety results

Table 12 shows the cost proportion of each safety program's subsets. It also indicates the safety cost ratio in terms of construction area concluded from a case study on a commercial building. The whole safety program consumes just 1.13% of the total construction budget. Meanwhile, around 84% of this cost is allocated to retain structures. Gurcanli's survey [14] of safety costs proves that this rate is fairly logical for the researchers' case study. Another striking point is that safety training accounts for just 2.62% of safety budget. On the other hand, the expert team believes that training has a notable impact on the project safety level.

These ratios seem economical to accept a safety program in a construction project. If project managers compare the low rate of safety program with construction accidents and their repercussions, they will be convinced to put money into safety programs; while, decision making is one of the key factors in modern construction industry [28]. Clearly, making the outcome of a safety program obvious for the people in charge of projects can definitely raise such programs' acceptability. To do so, it is necessary to investigate the result of a safety program which defines the risks of hazards. Table 12 demonstrates that the safety cost of each meter of construction area is just 6.2$, and that if retaining structures is considered as a work item, this amount will reduce to 0.97$.

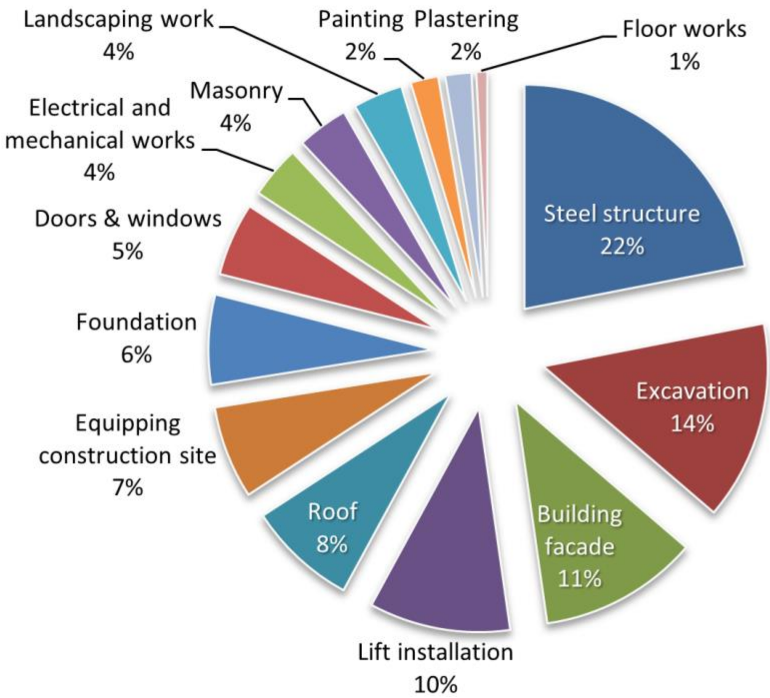


Figure 8. Total proportion of safety risk for each work item

Table 12: Safety program cost's details

	Safety Cost Percent (excluding retaining structure)	Safety Cost Percent	Construction Cost Percent	Cost Per Total Construction Area (USD/m²)
PPE	37.67	5.88	0.07	0.37
Safety Measures (except retaining structures)	45.55	7.11	0.08	0.44
Retaining Structures	_	84.39	0.96	5.23
Safety Training	16.78	2.62	0.03	0.16
Whole Safety Program	100.00	100.00	1.14	6.20

Table 13 indicates the details of a safety program in terms of work items. In this table the proportions do not account for 'Retaining Structures Cost' because some of construction experts believe that this safety action is a work item whereas others believe that it is one of the safety program's parts. However, the expert team suggests considering it as a safety program's subset. Based on Table 13 and Fig. 8, although Roof and Lift Installation items consume just 2% of safety costs, they make up 22% of the whole safety risks. Controlling such amount of risk by spending just 2% of the safety budget indicates that investing in the safety of these items will achieve the most efficiency in comparison with other items.

Table 13: Total proportion of safety program (except retaining structures) for each work item

Work item	Safety cost percent
Steel Structure	26.87
Roof	11.21
Doors &Windows	10.16
Masonry	8.06
Equipping Construction Site	7.80
Building Facade	5.24
Lift Installation	4.52
Excavation	4.33
Foundation	3.93
Painting	3.87
Plastering	3.80
Floor Works	3.74
Electrical and Mechanical Works	3.41
Landscaping Work	3.08

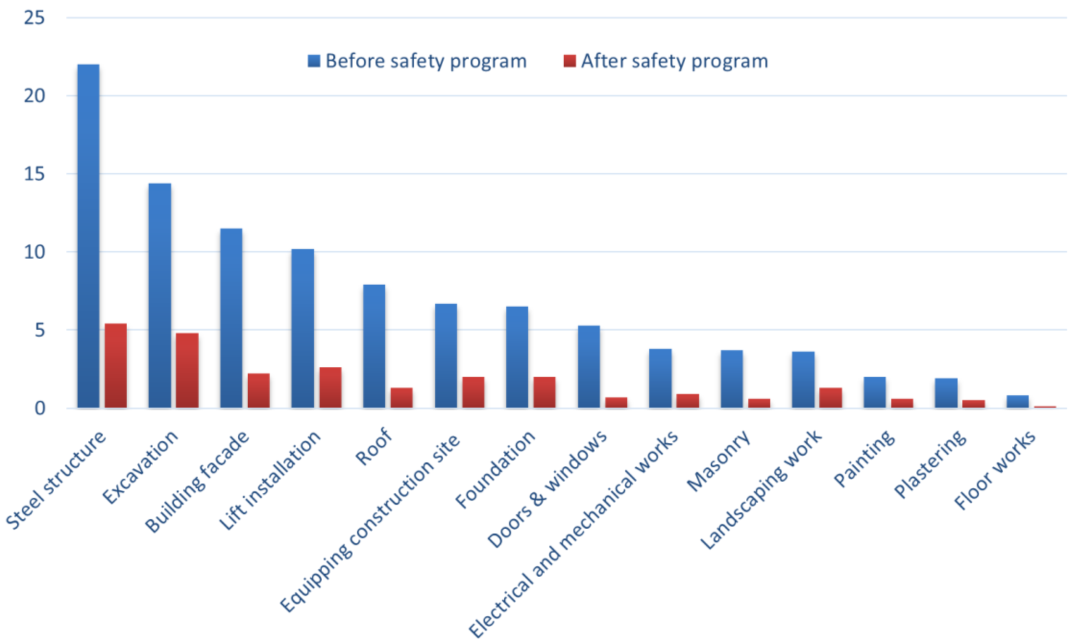


Figure 9. Safety risk percentage and the effect of safety program on each work item

The efficiency of safety program has always sparked a question in the minds of project managers. In order to survey this subject; a series of interviews was conducted. The expert team determined that how much a safety program can reduce each hazard's risk. The overall results are mentioned in Fig. 9. This figure shows the amount of safety risk in each work item and the amount of those risks as a result of choosing a safety program as the remedy for controlling them. All in all, 75% of total safety risks are reduced and just 25% of these risks remain unchanged after being dealt with. It is impossible to omit all the risks; hence project managers should inevitably choose the most efficient way to reduce the majority of risks with the least possible cost. Through using the defined safety program in this case study, 75% of risks were controlled by allocating just 1.13% of construction budget.

4.3 Results validation

After finishing the research, the results have to be validated. In order to do so, a group of experts were chosen in a way that none of them participated in the process of this research as a member of the expert team. Five experts were selected, and some interviews were conducted in order to check the validity of results. Experts use Table 14 to define the accuracy level of the results based on their knowledge and experience. Dewlaney [9] used a similar way to prove the validity of his research's results. He mentioned that if experts agree with the results around 80% or more, the accuracy and validity of the results will be proved. At the end of this step, experts confirmed the results at 90% and just 10% of disagreement existed. Table 14 shows the details of validation process in which disagreement rate is less than 20%. Thus the results of this research can be considered 'quite valid'.

Table 14: Score of results' validity levels

Results validity	Score
Very High	10 9
High	8 7
Moderate	6 5
low	4 3
very low	2 1

Table 15: The results of validation process

Results	Average score
Identification	9.4
Assessment	8.8
New Method of Assessment	9.2
Safety Program	9
Influence of Safety Program	8.6
Total Average	9

5. CONCLUSIONS

This article presents a new method for risk assessment which is flexible enough to adapt itself with the project conditions and provides more accurately real results by considering project conditions. A risk assessment method was developed to have such an ability considering HVN's parameter. This method makes the risk equation useable for other construction fields or even other industries too. Another innovation of this research is using PERT method to define hazards severity; similar incidents never have similar outputs since numerous factors affect them. PERT method can consider either optimistic or pessimistic results besides the normal possible ones.

Safety risks investigation shows that considering the number of defined risks and primary work items such as 'Excavation' and 'Steel Structure' constitute a considerable number of risks in comparison with other items. When it comes to the criticality of risks, 'Steel Structure', 'Building Façade' and 'Lift Installation' account for the most critical hazards due to the possibility of 'Fall to Lower Levels' and 'Struck by Falling Objects' accidents. One of the most significant results is that the most influential factors which affect safety risks in building construction projects are 'Proficiency and Workers' Experience', 'Complexity of Construction Technology' and 'Time limitation'.

The most necessary safety program for construction industry must have three subsets: PPEs, Safety Measures and Safety Training. By spending less than 1.5% of construction budget, project managers can provide such safety programs as well as reducing about 75% of the total safety risks. Safety training consumes just 3% of safety costs, but it has remarkable effects on the safety level of projects. In terms of efficiency of safety program, "Lift Installation" and "Building Facade" make up 22% of safety risks, but consume just 2% of safety costs. Thus they are the most justified items for safety investment.

In order to carry out further research, researchers should focus on defining the most influential factors which influence safety risks in other fields of construction such as dam, tunnel, highway, and etc. Further functional research can concentrate on the details of safety program, particularly on defining the influence of each part of the program on reducing safety risks. For instance, researchers may try to determine how much safety training reduces safety risks or how much it increases the safety level.

Acknowledgments: The writers appreciate Dr. Hassan Malekitabar's support and help during all steps of this research.

NOTATION

The following symbols are used in this paper:

RPN= Risk priority number
HVN= Hybrid value number
P= Probability
S= Severity
W_P= Weight of proficiency and workers' experience factor
F_P= Value of proficiency and workers' experience factor

W_C= Weight of complexity of construction technology factor
F_C= Value of complexity of construction technology factor
W_T= Weight of time limitation factor
F_T= Value of time limitation factor

REFERENCES

1. Nasirzadeh F. *Project Risk Management by Dynamic System Approach*, PhD thesis, Iran University of Science and Technology, Tehran, 2007.
2. Everett JG, Frank PB. Costs of accidents and injuries to the construction industry, *J Constr Eng Manag* 1996; **122**(2): 158-64.
3. Zhou Z, Goh YM, Li Q. Overview and analysis of safety management studies in the construction industry, *Safety Sci* 2015; **72**: 337-50.
4. Afshar A, Zolfaghar Dolabi HR. Multi-objective optimization of time-cost-safety using genetic algorithm, *Int J Optim Civil Eng* 2014; **4**(4): 433-50
5. Atashgah KM. Risk assessment and cost estimation in building project in construction phase, MSc thesis, Iran University of Science and Technology, Tehran, 2016.
6. Mamaghani BJ. OHSAS 18001 clarification, Azadeh publication, Tehran, 2004.
7. Cheng CW, Leu SS, Lin CC, Chihhao F. Characteristic analysis of occupational accidents at small construction enterprises, *Saf Sci* 2010; **48**(6): 698-707.
8. Memarian B, Mitropoulos P. Safety incidents and high-risk activities of masonry construction, *ASCE Construct Res Congr* 2012: 2510-9.
9. Dewlaney K, Hallowell M, Fortunato III B. Safety risk quantification for high performance sustainable building construction, *J Construct Eng Manag* 2012; **138**(8): 964-71.
10. Sun Y, Fang D, Wang S, Dai M, Lv X. Safety risk identification and assessment for Beijing Olympic venues construction, *J Manag Eng* 2008; 40-7.
11. Fung I, Tam V, Lo T, Lu L. Developing a risk assessment model for construction safety, *Int J Project Manag* 2010; **28**: 593-600.
12. Hallowell MR, Gambatese JA. Activity-based safety and health risk quantification for formwork construction, *J Construct Eng Manag* 2009; 135(10): 990-8.
13. Kim H, Lee H, Park M, Lee K. Influence factor-based safety risk assessment methodology for construction site, *ASCE Construct Rese Congr* 2010: 1356-1365.
14. Gurcanli GE, Bilir S, Sevim M. Activity based risk assessment and safety cost estimation for residential building construction projects, *Saf Sci* 2015; **80**: 1-12.
15. Al-Anbari S, Khalina A, Alnuaimi A, Normariah A, Yahya A. Risk assessment of safety and health (RASH) for building construction, *Proc Saf Environ Protec* 2015; **95**: 149-58.
16. Waehrer GM, Dong XS, Miller T, Haile E, Men Y. Costs of occupational injuries in construction in the United States, *Accid Anal Prev* 2007; **39**: 1258-66.
17. Pellicer E, Carvajal GI, Rubio MC, Catala J. A method to estimate occupational health and safety cost in construction projects, *KSCE J Civil Eng* 2014; **18**(7): 1955-65.
18. Sousa V, Almeida NM, Dias LA. Risk-based management of occupational safety and health in the construction industry – Part 2: Quantitative model, *Saf Sci* 2015; **74**: 184-94.
19. Ikpe E, Hammond F, Proverbs D. A cost-benefit analysis (CBA) of construction health and safety management: a theoretical discussion. *Procs 24th Annual ARCOM Conference*, Association of research in construction management, 2008, pp. 1035-1043.

20. Hallowell MR. Risk-based framework for safety investment in construction organization, *J Constr Eng Manage* 2011; **137**(8): 592-9.
21. Lopez-Alonso M, Davila MP, Gamez MC, Munoz TG. The impact of health and safety investment on construction company costs, *Saf Sci* 2013; **60**: 151-9.
22. Sarireh M, Tarawneh S. Safety concept, value and cost in construction projects in Jordan, *Civil Environ Res* 2014; **6**(5): 60-70.
23. Haj-Shirmohammadi A. Project control and management, Arkaneh-Danesh publication, Isfahan, 2014.
24. Ravanshadnia M. Reference book of safety management in construction projects, Simaye-Danesh publication, Tehran, 2014.
25. Fortunato III B, Hallowell M, Behm M, Dewlaney K. Identification of safety risks for high-performance sustainable construction projects, *J Construct Eng Manag* 2012; 138(4): 499-508.
26. Axelrod R. Structure of decision. The cognitive map of political elites, Princeton university press, Princeton, 1976.
27. Chen C.Using dematel method for medical tourism development in Taiwan, American *J Tourism Res* 2012; **1**(1): 26-32.
28. Valli P, Antony Jeyasehar C. Genetic algorithm based equipment selection method for construction project using matlab tool, *Int J Optim Civil Eng* 2012; **2**(2): 235-46.