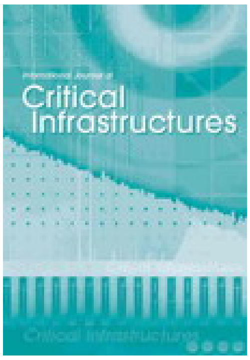


International Journal of Critical Infrastructures

ISSN online: 1741-8038 - ISSN print: 1475-3219
https://www.inderscience.com/ijcis

Utilising the fuzzy analytic network process technique to prioritise safety challenges in construction projects

Mostafa Pouyakian, Ali Akbar Shafikhani, Amir Abbas Najafi, Behrouz Afshar-Najafi, Amir Kavousi

DOI: 10.1504/IJCIS.2024.10047707

Article History:

Received:	02 September 2021
Accepted:	03 December 2021
Published online:	26 January 2024

Utilising the fuzzy analytic network process technique to prioritise safety challenges in construction projects

Mostafa Pouyakian and Ali Akbar Shafikhani*

Department of Occupational Health Engineering,
School of Public Health and Safety,
Shahid Beheshti University of Medical Sciences,
Tehran, Iran
Email: pouyakian@sbmu.ac.ir
Email: ali.shafikhani@yahoo.com
*Corresponding author

Amir Abbas Najafi

Department of Industrial Engineering,
K.N. Toosi University of Technology,
Tehran, Iran
Email: aanajafi@kntu.ac.ir

Behrouz Afshar-Najafi

Department of Industrial Engineering,
Islamic Azad University,
Qazvin Branch, Qazvin, Iran
Email: behrouz.afshar@gmail.com

Amir Kavousi

Department of Epidemiology,
School of Public Health and Safety,
Shahid Beheshti University of Medical Sciences,
Tehran, Iran
Email: kavousi@sbmu.ac.ir

Abstract: This study aims to identify and rank the obstacles to implementing a safety program in the Iranian construction industry. The obstacles were identified through literature review and interviews with experts in the Iranian construction industry. Because of the complex structure of the relationships between the obstacles and their mutual effects, the fuzzy analysis network Process method was used to model them. Obstacles to safety implementation were identified and ranked using the proposed model. Fourteen obstacles were identified in the three organisational, contractors, and systems dimensions. The most critical obstacles include tight project schedules, resource constraints, fierce competition between contractors to reduce time and cost. This study showed that the Iranian construction industry, despite its advantages, faces obstacles in the successful implementation of safety programs. It seems that the identified obstacles can be removed by modelling the safety program in project scheduling. However, more studies are needed in this area.

Keywords: safety; accidents; construction; analytic network process; ANP; fuzzy evaluation.

Reference to this paper should be made as follows: Pouyakian, M., Shafikhani, A.A., Najafi, A.A., Afshar-Najafi, B. and Kavousi, A. (2024) 'Utilising the fuzzy analytic network process technique to prioritise safety challenges in construction projects', *Int. J. Critical Infrastructures*, Vol. 20, No. 1, pp.16–32.

Biographical notes: Mostafa Pouyakian obtained his PhD in Occupational Health and Safety Engineering, in 2013. He currently works as an Associate Professor at the School of Public Health and Safety, Shahid Beheshti University of Medical Sciences, Tehran, Iran. His interesting research areas are safety science, risk assessment and management and human-machine interaction. He also has served as the Secretary of the board of the Iranian Ergonomics Society since 2013.

Ali Akbar Shafikhani received his MS in Occupational Health and Safety Engineering from the Hamedan University of Medical Sciences, in 2012. He is currently a PhD student of Occupational Health and Safety Engineering at the Shahid Beheshti University of Medical Sciences, Tehran, Iran. He works as a researcher at the research centre, Qazvin University of Medical Sciences, Iran. His research interests include industrial safety, ergonomics, risk assessment, and project scheduling and management.

Amir Abbas Najafi received his BS in Industrial Engineering from the Isfahan University of Technology in 1996, and MS and PhD in Industrial Engineering from Sharif University of Technology, in 1998 and 2005, respectively. He is currently an Associate Professor of Industrial Engineering at the K.N. Toosi University of Technology. His research interests include financial machine learning, portfolio selection models, project scheduling and management and applied operations research.

Behrouz Afshar-Najafi received his BS in Industrial Engineering from the Islamic Azad University, Qazvin Branch, Iran in 2001 and MS and PhD in Industrial Engineering from Sharif University of Technology, in 2003 and 2008, respectively. He is currently an Associate Professor of Industrial Engineering at the Islamic Azad University, Qazvin Branch, Iran. His research interests include financial machine learning, portfolio selection models, project scheduling and management and applied operations research.

Amir Kavousi has obtained his BA in Statistics from the Shiraz University and MS and PhD from Tarbiat Modares University. He is a Professor in Statistics at the Shahid Beheshti University of Medical Sciences and member of Department of Epidemiology. His topics of interest are Bayesian statistics and the analysis of spatial data in health and medicine. He is a Scientific Center for Spatial Statistics member at the Tarbiat Modares University.

1 Introduction

The construction industry is one of the most dangerous industries in the world (Pourmazaherian et al., 2021; Nassar and Hussein, 2021; Fonseca, 2021). In the USA, the number of fatal injuries in the construction industry increased by 16% from 2011 to 2014 (Statistics, 2016). This trend has been increasing in recent years, so that in 2015, 2016, 2017, and 2018, the death toll has reached 985, 1,034, 1,013 and 1,038, respectively (De la Fuente et al., 2014).

Construction companies utilise the project management concept to plan, organise, execute and control their project's progress. Project management plays a significant role in the project's timely completion under the approved budget and schedule (Ernest, 2014). Different methodologies have been used for safety interventions in the construction industry. These interventions include safety integration in project management (Badri, 2015; Castings, 2018), site layout planning (Kaveh et al., 2018; Long et al., 2019), and safety interventions based on project scheduling (Li et al., 2017; Ferreira et al., 2019). Despite these methods, we still see accidents in these industries.

Different opinions exist about the causes of accidents in the construction industry; these shortcomings can prevent the implementation of practical solutions. This study aims to identify and rank the obstacles to implementing safety programs in the Iranian construction industry. Intervention strategies can be considered depending on the significance and priority of these obstacles, enabling the successful implementation of such safety programs. These obstacles are complex because they differ from one author to another and affect each other. In this case, the usual methods of identifying and ranking problems are inadequate; thus, it is necessary to use other methods to identify and rank them. This study used a modelling approach using the analytic network process (ANP) method to identify and rank the challenges facing safety. Fuzzy numbers were used instead of crisp numbers to overcome the associated problems and limitations when measuring these obstacles.

2 Literature review

Insufficient resources are one of the obstacles that can negatively affect safety programs. In projects, these resources are in the form of non-renewable resources (materials and money, etc.) and renewable resources (workforce and equipment). One of the most critical activity risk factors is the equipment risk factor. Equipment unavailability shifts the activity time to another time and affects the management of safety risks (Kogi, 2002; Goh and Chua, 2013; Yiu et al., 2018; Buniya et al., 2021).

Another obstacle to implementing safety plans is the tight project schedule. This obstacle is also one of the most challenging obstacles to safety management in the construction sector in Hong Kong. Currently, most stakeholders use the penalty scheme for any delay in the project contract, which causes contractors to execute the project schedule tightly to avoid the additional overhead of project delays (Goh and Chua, 2013; Ju and Rowlinson, 2014; Yiu et al., 2018; Buniya et al., 2021).

Another important reason for the high rate of accidents in the construction industry is the management's lack of commitment to occupational safety and health (OSH) and less priority to OSH (compared to other goals). Commitment to safety depends on the level of safety awareness, which in turn affects its prioritisation. Assigning a lower priority to safety leads to weak safety culture (Goh and Chua, 2013; Yiu et al., 2018).

Another obstacle is that the current project management system focuses more on time and cost and places safety planning solely on safety personnel. This perception implies that safety is unique and that the system is such that it separates safety management from other goals of project management. This causes any safety intervention in the project implementation phase to be ignored. In other words, the safety management system is no longer integrated with the project management (Fan et al., 2014; Yiu et al., 2018, 2019). In addition, limited awareness of safety considerations at higher management levels affects perceptions and strategies of safety and risk management throughout the organisation (Kogi, 2002; Stephen and Hunt, 2002).

Table 1 Summarises the limitations of safety enforcement in the construction industry

Obstacles to construction projects	*Kartam et al. (2000)*	*Stephen and Hunt (2002)*	*Kogi (2002)*	*Fang et al. (2006)*	*Goh and Chua (2013)*
Low priority for safety and health		*	*		
Lack of proper training of workers, lack of conception of risk, or insufficient safety knowledge	*		*		
Current project management systems focus on other goals rather than safety		*			
Tight project schedule					*
Resource constraints are an obstacle to dynamic risk management			*		*
Rigid management style		*		*	
Lack of management commitment to OSH					*
Non-use of qualified workers					
Poor safety culture					
Competition between contractors to reduce time and cost					
High turnover of workers					
Inconsistency of the contractor's safety and health management system with the subcontractor					

Obstacles to construction projects	*Ju and Rowlinson (2014)*	*Sunindijo (2015)*	*Yiu et al. (2018)*	*Yiu et al. (2019)*	*Buniya et al. (2021)*
Low priority for safety and health			*		*
Lack of proper training of workers, lack of conception of risk, or insufficient safety knowledge				*	
Current project management systems focus on other goals rather than safety			*		
Tight project schedule	*		*		*

Table 1 Summarises the limitations of safety enforcement in the construction industry (continued)

Obstacles to construction projects	*Kartam et al. (2000)*	*Stephen and Hunt (2002)*	*Kogi (2002)*	*Fang et al. (2006)*	*Goh and Chua (2013)*
Resource constraints are an obstacle to dynamic risk management			*		*
Rigid management style			*		
Lack of management commitment to OSH			*		
Non-use of qualified workers			*		
Poor safety culture		*			
Competition between contractors to reduce time and cost		*			
High turnover of workers			*	*	
Inconsistency of the contractor's safety and health management system with the subcontractor				*	

Some studies consider the lack of safety training the most common safety issue. Studies have shown that safety education is essential to prevent and reduce accidents. The shortage of skilled workers due to poor safety awareness and insufficient knowledge of how to work safely leads to poor safety behaviours (Kartam et al., 2000; Yiu et al., 2019). Table 1 summarises the limitations of safety enforcement in the construction industry.

3 Methods and materials

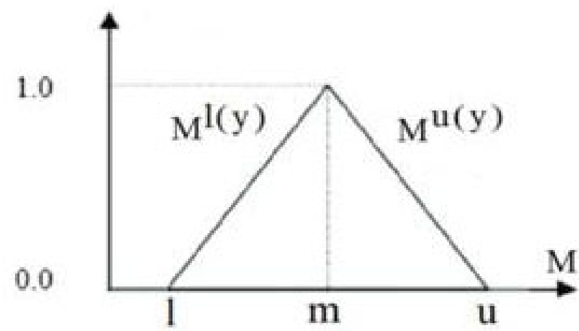
First, a literature review was conducted to identify the challenges to implementing safety programs. In the next stage, interviews were conducted with 16 experts in the construction industry in Iran. The specialists had at least seven years of experience in the construction industry. Experts analysed challenges from the perspective of developing countries such as Iran. The purpose of interviewing experts was to examine existing obstacles (extracted from the literature review) and identify potential obstacles that had not been identified previously. They identified several potential obstacles and confirmed that the selected obstacles were related to the Iranian construction industry.

The fuzzy analytic network process (FANP) method was used in the present study to rank the challenges facing safety implementation in construction firms (Ozdemir et al., 2021; Pang et al., 2021). An ANP model consists of a network of criteria, sub-criteria, and options grouped in a cluster. Various methods have been proposed for FANP. These methods have a systematic approach used in fuzzy problems and the structure of network analysis to select alternatives. Due to the need to use pairwise comparisons in the network analysis process; also, considering the main objective of the problem, which is to use fuzzy theory to eliminate the shortcomings in using inaccurate opinions of decision-makers in determining the relative importance of criteria and sub-criteria; thus, Chang's method was used in this study (Mohammadfam et al., 2015, 2017).

Chang's method $M_{gi}^{j} (j = 1, 2, .., m; i = 1, 2, .., n)$ is based on the fuzzy triangular number. Each triangular fuzzy number has a linear representation on its left and right, whose membership function can be defined as follows. Figure 1 shows a fuzzy triangular number.

$$\mu\left(x/\tilde{M}\right) = \begin{cases} 0, & x < l, \\ (x-l)/(m-l), & l \le x \le m, \\ (u-x)/(u-m), & m \le x \le u, \\ 0, & x < u. \end{cases} \quad (1)$$

Figure 1 Shows a triangular fuzzy number



The steps to obtain the local weight of the criteria and sub-criteria in this method are as follows:

Step 1 The value of fuzzy extent for the i^{th} object is defined as follows:

$$s_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \quad (2)$$

To calculate $\sum_{j=1}^{m} M_{gi}^{j}, \sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}, \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1}$, we follow the following formulas.

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \quad (3)$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i \right) \quad (4)$$

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \right) \quad (5)$$

Step 2 The degree of possibility $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ is defined as follows:

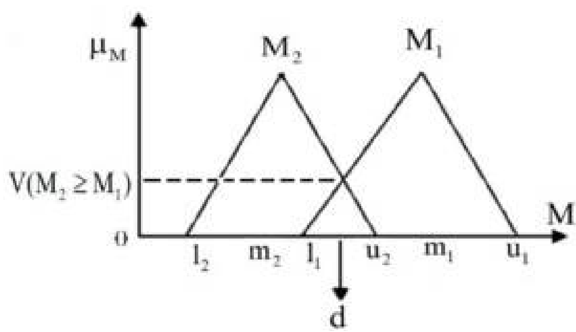
$$V(M_2 \geq M_1) = SUP\left[\min\left(\mu_{M1}(x), \mu_{M2}(y)\right)\right] \quad (6)$$

And its equation is defined as follows:

$$V(M_2 \geq M_1) = hgt(M_2 \cap M_1) = \mu_{M2}(d) = \begin{cases} 1, & \text{if } m_2 \geq m_1, \\ 0, & \text{if } l_1 \geq u_2, \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{otherwise,} \end{cases} \quad (7)$$

where d is the ordinate of the highest intersection point D between μ_{M1} and μ_{M2}:

Figure 2 Intersection between M_1, M_2



To compare M_1, M_2 we need both the values of $V(M_2 \geq M_1)$ and $V(M_1 \geq M_2)$.

Step 3 The degree of possibility for a convex fuzzy number greater than K convex fuzzy number is defined as follows:

$$\begin{aligned} V(M \geq M_1, M_2, ..., M_k) &= V\left[(M \geq M_1) \text{ and } (M \geq M_2) \textit{ and } ... \textit{ and} (M \geq M_k)\right] \\ &= \min V(M \geq M_i), i = 1, 2, ..., k \end{aligned} \quad (8)$$

Assume that:

$$d'(A_i) = \min V(S_i \geq S_K), \text{ for } K = 1, 2, ..., n; k \neq i \quad (9)$$

Therefore, the weights of the vectors are obtained as follows:

$$W' = \min\left(d'(A_1), d'(A_2), ..., d'(A_n)\right)^T, \quad (10)$$

where Ai (i = 1, 2, …, n) are the same n elements.

Step 4 Normalisation: the weight of normalised factors is obtained as follows:

$$W = \left(d(A_1), d(A_2), ..., d(A_n)\right)^T \quad (11)$$

where W is a non-fuzzy number.

The proposed model was developed to identify and rank the challenges of safety implementation in project-oriented companies in the following seven steps:

- Step 1: Identify the factors and sub-factors used in the model.
- Step 2: Build an ANP model hierarchy that includes goal setting, factors, and sub-factors.
- Step 3: The local weights of the factors and sub-factors were determined using the pairwise comparison matrix. It should be noted that fuzzy scales for determining the relative importance of weights are given in Table 2 based on research by Kahraman et al. (2006).
- Step 4: Using the fuzzy scales presented in Table 2, the inner dependence matrix of each factor relative to the other factor was calculated. The inner dependence matrix was multiplied by the local weight of the factors obtained in Step 3 to obtain the interdependent weights of the factors. The dependence between the factors was determined by analysing the effects of each factor on the other factor using pairwise comparisons.
- Steps 5 and 6: Calculate the global weights for the sub-factors by multiplying the local weight of the sub-factors (Step 3) by the interdependent weights of the factors (Step 4) to which it belongs.
- Step 7: At this stage, the challenges of safety implementation in project-oriented companies were ranked using the global weight of the following factors.

Table 2 Language scale to express the degree of importance

Linguistic scale for importance	*Triangular fuzzy numbers*	*Inverse fuzzy numbers*
Just equal	(1, 1, 1)	(1, 1, 1)
Equally important (EI)	(1/2, 1, 3/2)	(2/3, 1, 2)
Weakly more important (WMI)	(1, 3/2, 2)	(1/2, 2/3, 1)
Strongly more important (SMI)	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Very strongly more important (VSMI)	(2, 5/2, 3)	(1/3, 2/5, 1/2)
Absolutely more important (AMI)	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)

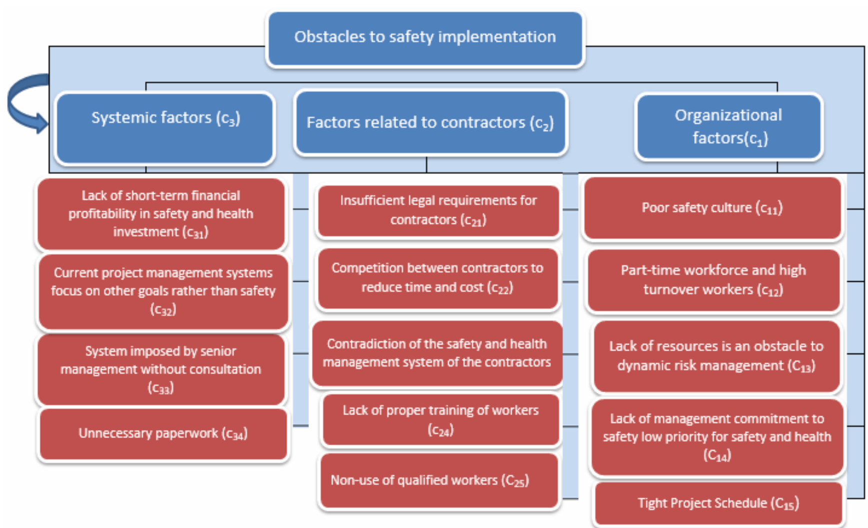
4 Results

Findings from the implementation of the study based on the steps above are presented in the following section:

Step 1 For modelling, several obstacles related to developing countries were first selected from the obstacles identified from different sources. The decision-making committee then assessed these obstacles using the fuzzy Delphi method (Bui et al., 2020). Finally, 14 factors were classified into three groups: organisational-related factors, contractors, and safety systems. In addition to the obstacles in Table 1, four obstacles were added to the obstacles by experts. These obstacles included 'system imposed by senior management without consultation', 'unnecessary paperwork', 'lack of short-term financial benefits in safety and health investment' and 'insufficient legal requirements for contractors'.

Step 2 The ANP model formed by the elements specified in Step 1 is shown in Figure 3. The model consists of three parts. The first part is the goal, and the second and third parts consist of criteria and sub-criteria, respectively. The aim is to identify and rank the challenges facing safety enforcement in Iran. In the second part, the criteria are classified into clusters, including three sections: organisational factors, contractors, and factors related to the company's safety and project management system. The criteria of the second part are related to the goal and sub-criteria by a directional vector (external dependence). In addition, the elements within this cluster are internally related to each other (internal dependence).

Figure 3 Factors and sub-factors for obstacles to implement the safety program (see online version for colours)



In other words, other organisational factors, contractors, and the safety system also affect each other, the effect of which will be considered in the model. The arc shown in the second section in Figure 3 shows the internal dependence between the factors. The following criteria are shown in the third section. In other words, the following sub-factors are evaluated in this section, which are the same elements specified in Step 1. These sub-factors include a poor safety culture in the industry, especially among small companies, part-time workforce and high workforce turnover, resource constraints (constraint of equipment and other resource constraints) as an obstacle to dynamic risk management, senior management's lack of commitment to OSH and giving less priority to OSH, tight project schedule, insufficient legal requirements for contractors, fierce competition between contractors to reduce time and cost, inconsistency of the contractor's and sub-contractors safety and health management systems, lack of proper worker training, lack of qualified workers, no short-term financial gain in

OSH investment systems, the focus of project management systems on other goals instead of safety, the system imposed by senior management without consultation, and administrative formalities (paperwork) are high.

Table 3 Local weights and pairwise comparison matrix of main factors

Factors	C_1	C_2	C_3	*Local weights*
C_1	(1, 1, 1)	(1/2, 1, 3/2)	(1, 3/2, 2)	0.37
C_2	(2/3, 1, 2)	(1, 1, 1)	(1/2, 1, 3/2)	0.33
C_3	(1/2, 2/3, 1)	(2/3, 1, 2)	(1, 1, 1)	0.3

Notes: Calculate the local weight vector

S_{C1} = (2.5, 3.5, 4.5) ⊗ (1/13, 1/9.17, 1/6.83) = (0.19, 0.38, 0.66),
S_{C2} = (2.17, 3, 4.5) ⊗ (1/13, 1/9.17, 1/6.83) = (0.17, 0.33, 0.66),
S_{C3} = (2.17, 2.67, 4) ⊗ (1/13, 1/9.17, 1/6.83) = (0.17, 0.3, 0.59).
$V(S_{C1} \geq S_{C2}) = 1.00$,
$V(S_{C1} \geq S_{C3}) = 1.00$,
$V(S_{C2} \geq S_{C1}) = 0.90$,
$V(S_{C2} \geq S_{C3}) = 1.00$,
$V(S_{C3} \geq S_{C1}) = 0.81$,
$V(S_{C3} \geq S_{C2}) = 0.92$.

Table 4 Local weights and pairwise comparison matrix of organisational sub-factor

Organisational sub-factor	$C_{1.1}$	$C_{1.2}$	$C_{1.3}$	$C_{1.4}$	$C_{1.5}$	*Local weights*
$C_{1.1}$	(1, 1, 1)	(2/3, 1, 2)	(2/5, 1/2, 2/3)	(1/2, 1, 3/2)	(2/5, 1/2, 2/3)	0.12
$C_{1.2}$	(1/2, 1, 3/2)	(1, 1, 1)	(1/2, 2/3, 1)	(1, 3/2, 2)	(1/2, 2/3, 1)	0.17
$C_{1.3}$	(3/2, 2, 5/2)	(1, 3/2, 2)	(1, 1, 1)	(3/2, 2, 5/2)	(1, 1, 1)	0.30
$C_{1.4}$	(2/3, 1, 2)	(1/2, 2/3, 1)	(2/5, 1/2, 2/3)	(1, 1, 1)	(1/3, 2/5, ½)	0.0.9
$C_{1.5}$	(3/2, 2, 5/2)	(1, 3/2, 2)	(1, 1, 1)	(2, 5/2, 3)	(1, 1, 1)	0.32

Table 5 Local weights and pairwise comparison matrix of contractors sub-factor

Contractors sub-factor	$C_{2.1}$	$C_{2.2}$	$C_{2.3}$	$C_{2.4}$	$C_{2.5}$	*Local weights*
$C_{2.1}$	(1, 1, 1)	(1/3, 2/5, 1/2)	(2/3, 1, 2)	(2/5, 1/2, 2/3)	(1/2, 2/3, 1)	0.09
$C_{2.2}$	(2, 5/2, 3)	(1, 1, 1)	(2, 5/2, 3)	(1/2, 1, 3/2)	(1, 3/2, 2)	0.33
$C_{2.3}$	(1/2, 1, 3/2)	(1/3, 2/5, 1/2)	(1, 1, 1)	(1/2, 2/3, 1)	(2/5, 1/2, 2/3)	0.07
$C_{2.4}$	(3/2, 2, 5/2)	(2/3, 1, 2)	(1, 3/2, 2)	(1, 1, 1)	(1/2, 1, 3/2)	0.26
$C_{2.5}$	(1, 3/2, 2)	(1/2, 2/3, 1)	(3/2, 2, 5/2)	(2/3, 1, 2)	(1, 1, 1)	0.24

Step 3 The fuzzy scale to determine the relative importance of the weights is given in Table 2. At this stage, the weight of factors and sub-factors shown in the second

and third parts of the model, shown in Figure 3, was calculated. This is achieved through a pairwise comparison matrix by the decision-making committee using the scales given in Table 2. An example of a pairwise comparison matrix is shown in Tables 3, 4, 5, and 6 with local weights:

Table 6 Local weights and pairwise comparison matrix of Systemic sub-factor

Systemic factors	$C_{3.1}$	$C_{3.2}$	$C_{3.3}$	$C_{3.4}$	*Local weights*
$C_{3.1}$	(1, 1, 1)	(1/2, 2/3, 1)	(1,1,1)	(1, 3/2, 2)	0.24
$C_{3.2}$	(1, 3/2, 2)	(1, 1, 1)	(1/2, 1, 3/2)	(3/2, 2, 5/2)	0.35
$C_{3.3}$	(1, 1, 1)	(2/3, 1, 2)	(1, 1, 1)	(1, 3/2, 2)	0.28
$C_{3.4}$	(1/2, 2/3, 1)	(2/5, 1/2, 2/3)	(1/2, 2/3, 1)	(1, 1, 1)	0.12

Step 4 Using Table 2, the inner dependence matrix of each factor was determined relative to the other factors. This inner dependence matrix is multiplied by the weight of the factors obtained in Step 3 to obtain the weight of the inner dependence of the factors. The dependence between the factors is determined by analysing the effects of each factor on the other factor and using pairwise comparisons. Given the dependencies presented in the second part of the ANP model presented in Figure 3, examples of the pairwise comparison matrix for the factors are presented in Tables 7, 8 and 9. For example, the question 'what is the relative importance of contractor-related factors compared to system-related factors when the organisation-related factors are under control?' The 'very detailed significant' answer is equivalent to its triangular fuzzy number in Table 7 (1/2, 1, 3/2).

Table 7 Internal dependence matrix of factors according to organisational factors

C_1	C_2	C_3	*Relative importance weights*
C_2	(1, 1, 1)	(1/2, 1, 3/2)	0.5
C_3	(2/3, 1, 2)	(1, 1, 1)	0.5

Table 8 Internal dependence matrix of factors according to the factors of contractors

C_2	C_1	C_3	*Relative importance weights*
C_1	(1, 1, 1)	(3/2, 2, 2.5)	1
C_3	(2/5, 1/2, 2/3)	(1, 1, 1)	0

Table 9 Internal dependence matrix of factors with respect to systemic factors

C_2	C_1	C_3	*Relative importance weights*
C_1	(1, 1, 1)	(1, 3/2, 2)	0.69
C_2	(1/2, 2/3, 1)	(1, 1, 1)	0.31

As shown in Figure 4. As long as the correlation and relationship between the criteria were considered, there was a significant difference in the results, so that the factors related to the organisation from 0.37 to 0.45, the contractors' factors from 0.33 to 0.30, and the systemic factors from 0.30 to 0.25 were altered.

Figure 4 Matrix of weight dependence of the main factors

$$\begin{bmatrix} 1.00 & 1.00 & 0.69 \\ 0.50 & 1.00 & 0.31 \\ 0.50 & 0 & 1.00 \end{bmatrix} \times \begin{bmatrix} 0.37 \\ 0.33 \\ 0.30 \end{bmatrix} = \begin{bmatrix} 0.90 \\ 0.60 \\ 0.49 \end{bmatrix} \rightarrow \begin{bmatrix} 0.45 \\ 0.30 \\ 0.25 \end{bmatrix}$$

Steps 5 and 6 The final weight of the sub-factors is calculated by multiplying the local weight of the sub-factors (Step 3) by the inner dependence weight of the factors (Step 4), shown in Table 10.

Table 10 Calculation of global weight of sub-factors

Factors		*Sub-factors*	*Local weights*	*Global weights*
(0.45) Organisational factors (C1)	($C_{1.1}$)	Poor safety culture in industry, especially among small companies	0.12	0.06
	($C_{1.2}$)	Part-time workforce and high turnover workers	0.17	0.07
	($C_{1.3}$)	Resource constraints (equipment) are an obstacle to dynamic management risk	0.3	0.14
	($C_{1.4}$)	Lack of management commitment to OHS, low priority for safety and health	0.09	0.04
	($C_{1.5}$)	Tight Project schedule	0.32	0.15
(0.30) Factors contractors (C2)	($C_{2.1}$)	Insufficient legal requirements for contractors	0.09	0.03
	($C_{2.2}$)	Competition between contractors to reduce time and cost	0.33	0.1
	($C_{2.3}$)	inconsistency of the contractor's safety and health management system with the subcontractor	0.07	0.02
	($C_{2.4}$)	Lack of proper training of workers	0.26	0.08
	($C_{2.5}$)	Non-use of qualified workers	0.24	0.07
(0.25) Systemic factors (C3)	($C_{3.1}$)	Lack of short-term financial benefits in safety and health investment	0.24	0.06
	($C_{3.2}$)	Current project management systems focus on other goals rather than safety	0.35	0.09
	($C_{3.3}$)	System imposed by senior management without consultation	0.28	0.07
	($c_{3.4}$)	unnecessary paperwork	0.12	0.03

Step 7 In this step, the challenges (obstacles) of implementing safety in construction companies were prioritised in order of ranking using the global weight of the sub-factors (Table 10) and are shown in Table 11.

Table 11 Global weight of sub-factors in order of prioritisation rank

Sub-factors	*Global weights*	*Rank*
Tight project schedule ($C_{1.5}$)	0.15	1
Resource constraints are an obstacle to dynamic risk management ($C_{1.3}$)	0.14	2
Competition between contractors to reduce time and cost ($C_{2.2}$)	0.1	3
Current project management systems focus on other goals rather than safety ($C_{3.2}$)	0.09	4
Lack of proper training of workers ($C_{2.4}$)	0.08	5
Part-time workforce and high turnover of workers ($C_{1.2}$)	0.07	6
Non-use of qualified workers ($C_{2.5}$)	0.07	7
System imposed by senior management without consultation ($C_{3.3}$)	0.07	8
Lack of short-term financial benefits in safety and health investment ($C_{3.1}$)	0.06	9
Poor safety culture in industry, especially among small companies ($C_{1.1}$)	0.06	10
Lack of management commitment to safety and health and low priority for safety and health ($C_{1.4}$)	0.04	11
unnecessary paperwork ($C_{3.4}$)	0.03	12
Insufficient legal requirements for contractors ($C_{2.1}$)	0.03	13
inconsistency of the contractor's safety and health management system with the subcontractor ($C_{2.3}$)	0.02	14

5 Discussion

Despite its advantages, the Iranian construction industry faces obstacles in successfully implementing safety programs (Naderpour et al., 2019). This study identified 14 main obstacles in the three groups of organisations, contractors, and systems that must be overcome to support implementing safety programs in the Iranian construction industry. The results showed that the most critical obstacles include tight project schedule, resource constraints, fierce competition between contractors to reduce time and cost, the focus of current project management systems on other goals instead of safety, lack of proper worker training, part-time workforce, worker turnover, non-use of qualified workers and the system imposed by senior management without consultation.

Among the sub-criteria of organisational obstacles, the most critical identified obstacles were tight project planning and resource constraints (equipment and other resources). Other studies have achieved similar results in this regard and showed that the two obstacles are imperative to the implementation of the safety program (Goh and Chua, 2013; Buniya et al., 2021). Most construction companies now use a tight time management style to better control site improvements, as most work plans submitted by the client or main contractor are considered in a tight and limited time frame (Goh and Chua, 2013; Ju and Rowlinson, 2014). The mentioned limitation is an obstacle in implementing the safety management system. The consequence of such an obstacle increases workers' pressure and stress, which often leads to safety issues and reduced productivity (Goh and Chua, 2013; Ju and Rowlinson, 2014; Stephen and Hunt, 2002). Kogi (2002) and Goh and Chua (2013) also showed that some construction companies, especially those with smaller construction projects, have insufficient resources for their business purposes. This makes staff and project management less committed to OSH issues (Kogi, 2002; Goh and Chua, 2013).

Among the sub-criteria related to contractors, ‘fierce competition between contractors to reduce time and costs’ and ‘lack of proper worker training’ had the highest ratings. Fierce competition between contractors to reduce time and cost may cause them to resist safety changes because they feel that the methods developed in the safety management system are redundant and, in some cases, unnecessary (Sunindijo, 2015). The consequence of this action is that they make safety a lower priority than project time and cost, which is another limitation of this system (Sunindijo, 2015; Yiu et al., 2018). Another critical obstacle among the sub-criteria of contractors is the lack of proper worker training and insufficient time for worker training. Kartam et al. (2000) and Yiu et al. (2019) also reached common conclusions about the lack of proper worker training (Kartam et al., 2000; Yiu et al., 2019). They believed that the said factor was a significant obstacle to implementing the safety program. The reason for this should be stated, as the project has specific scheduling, penalty costs, and critical activities. It will not be possible to train staff at any time during project implementation, and safety training interventions need to be performed at specific stages of the project schedule that have a floating time (Yiu et al., 2018). This training should never be done in the path of critical activities in a project, as any delay in carrying out activities in this path will cause the project time and cost to exceed the specified amount set by the stakeholders.

In the subgroup of factors related to Safety systems and project management, the most critical obstacles were identified as sub-factors such as ‘focus of current project management systems on other goals instead of safety’ as well as ‘system imposed by senior management without consultation’. In a study by Yiu et al. (2018), eight obstacles were identified through structured interviews. These obstacles were mainly associated with project management and leadership. There is a need for adequate support from managers and the government for construction industries to ensure the safe completion of the project while observing the associated time, resources, and cost limitations (Suresh, 2017; Zou and Sunindijo, 2015). Therefore, in addition to the raised obstacles, management’s poor understanding of safety and health is another limitation. In Brazil, a 2018 study by Garnica and Barriga (2018) found that management tends to blame employees and government for implementing safety and health policies, while foreign actors tend to blame management and problems. They believe that problems result from a lack of resource allocation.

Further studies on the causality of identified obstacles and methods to prevent them are needed but can make suggestions according to the identified obstacles. As mentioned, the most critical obstacles identified in this study were related to tight scheduling and resource constraints. Although a tight project schedule may reduce direct costs, it does increase safety risk scores. On the other hand, the action of the safety management system to minimise the safety risk score may increase the project time and the total cost of the project (Koulinas et al., 2020; Yi and Langford, 2006). Therefore, a safety program effectively reduces the safety risk in such a complex situation. Given the identified obstacles, it is thought that contractor safety programs can be supported by modelling a safety program in integration project scheduling and equipment scheduling. Many studies are needed to prove such a hypothesis. If proper interventions are not implemented, the project team will focus on goals other than safety, and safety will be neglected.

6 Conclusions

This study showed that the Iranian construction industry, despite its advantages, faces obstacles in the successful implementation of safety programs. The analysis identified 14 obstacles in three dimensions (organisational, contractors, and system). The most critical obstacles include tight project schedule, resource constraints, and fierce competition between contractors to reduce time, and cost, the focus of current project management systems on other goals instead of safety goals, lack of proper worker training, part-time workforce, and high worker turnover, lack of qualified workers, and a system imposed by senior management without consultation. It seems that the identified obstacles can be removed by modelling the safety program in project scheduling. However, more studies are needed in this area. If the safety program is designed based on the identified obstacles, safety gradually becomes an integral part of construction project activities.

Acknowledgements

The authors would like to gratefully acknowledge Dr. Abbas Shafikhani, Lecturer at University and Project Manager at Nirou Moharekeh Machine Tools Company (NMT CO), for editing the manuscript. The authors acknowledge the immense help received from the scholars whose articles are cited and included in the reference of this manuscript. The authors are also grateful to the editors/publishers of all those articles, journals, and books from where the literature for this article had been reviewed and discussed.

References

Badri, A. (2015) 'The challenge of integrating OHS into industrial project risk management: Proposal of a methodological approach to guide future research (case of mining projects in Quebec, Canada)', *Minerals*, Vol. 5, No. 2, pp.314–334.

Bui, T.D., Tsai, F.M., Tseng, M-L. and Ali, M.H. (2020) 'Identifying sustainable solid waste management barriers in practice using the fuzzy Delphi method', *Resources, Conservation and Recycling*, Vol. 154, p.104625.

Buniya, M.K., Othman, I., Sunindijo, R.Y., Kineber, A.F., Mussi, E. and Ahmad, H. (2021) 'Barriers to safety program implementation in the construction industry', *Ain Shams Engineering Journal*, Vol. 12, No. 1, pp.65–72.

Castings, L. (2018) 'Integration of health, safety and environmental principles into industrial project management', *European Project Management Journal*, Vol. 8, No. 1, pp.33–39.

De la Fuente, V.S., López, M.A.C., González, I.F., Alcántara, O.J.G. and Ritzel, D.O. (2014) 'The impact of the economic crisis on occupational injuries', *Journal of Safety Research*, Vol. 48, pp.77–85.

Ernest, K. (2014) *Project Management Practices in the Ghanaian Building Industry*, Lap Lambert Academic Publishing GmbH KG, Saarbrücken, Germany.

Fan, D., Lo, C.K.Y., Ching, V. and Kan, C.W. (2014) 'Occupational health and safety issues in operations management: a systematic and citation network analysis review', *International Journal of Production Economics*, Vol. 158, pp.334–344.

Fang, D., Chen, Y. and Wong, L. (2006) 'Safety climate in construction industry: a case study in Hong Kong', *Journal of Construction Engineering and Management*, Vol. 132, No. 6, pp.573–584.

Ferreira, N., Santos, G. and Silva, R. (2019) 'Risk level reduction in construction sites: towards a computer aided methodology – a case study', *Applied Computing and Informatics*, Vol. 15, No. 2, pp.136–143.

Fonseca, E.D. (2021) 'Accident and innovation in construction industry: learning by doing to prevent accidents and improve the production', *Safety Science*, Vol. 142, p.105389.

Garnica, G.B. and Barriga, G.D.C. (2018) 'Barriers to occupational health and safety management in small Brazilian enterprises', *Production*, Vol. 28, p.e20170046.

Goh, Y.M. and Chua, D. (2013) 'Neural network analysis of construction safety management systems: a case study in Singapore', *Construction Management and Economics*, Vol. 31, No. 5, pp.460–470.

Ju, C. and Rowlinson, S. (2014) 'Institutional determinants of construction safety management strategies of contractors in Hong Kong', *Construction Management and Economics*, Vol. 32, Nos. 7–8, pp.725–736.

Kahraman, C., Ertay, T. and Büyüközkan, G. (2006) 'A fuzzy optimization model for QFD planning process using analytic network approach', *European Journal of Operational Research*, Vol. 171, No. 2, pp.390–411.

Kartam, N., Flood, I. and Koushki, P. (2000) 'Construction safety in Kuwait: issues, procedures, problems, and recommendations', *Safety Science*, Vol. 36, No. 3, pp.163–184.

Kaveh, A., Rastegar Moghaddam, M. and Khanzadi, M. (2018) 'Efficient multi-objective optimization algorithms for construction site layout problem', *Scientia Iranica*, Vol. 25, No. 4, pp.2051–2062.

Kogi, K. (2002) 'Work improvement and occupational safety and health management systems: common features and research needs', *Industrial Health*, Vol. 40, No. 2, pp.121–133.

Koulinas, G.K., Xanthopoulos, A.S., Tsilipiras, T.T. and Koulouriotis, D.E. (2020) 'Schedule delay risk analysis in construction projects with a simulation-based expert system', *Buildings*, Vol. 10, No. 8, p.134.

Li, S., Zhang, Z., Hu, K., Zhao, S. and Yan, X. (2017) 'Resource-constrained project scheduling in hazardous environment', *2017 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, IEEE, pp.2266–2270.

Long, L.D., Tran, D-H. and Nguyen, P.T. (2019) 'Hybrid multiple objective evolutionary algorithms for optimising multi-mode time, cost and risk trade-off problem', *International Journal of Computer Applications in Technology*, Vol. 60, No. 3, pp.203–214.

Mohammadfam, I., Shafikhani, A., Shafikhani, A.A. and Ghasemi, F. (2017) 'Determining a suitable risk-based maintenance strategy for improvement of the safety indices', *JHSW*, Vol. 7, No. 4, pp.279–290.

Mohammadfam, I., Shafikhani, A.A., Shafikhani, A. and Taheri, F. (2015) 'Providing an early warning framework to identify, assess and control the human performance influencing factor', *IOH*, Vol. 12, No. 5, pp.43–52.

Naderpour, H., Kheyroddin, A. and Mortazavi, S. (2019) 'Risk assessment in bridge construction projects in Iran using Monte Carlo simulation technique', *Practice Periodical on Structural Design and Construction*, November, Vol. 24, No. 4, p.04019026.

Nassar, Y.S. and Hussein, A.M. (2021) 'Identify and analyze the most important factors affecting the safety of employees in construction sites in Iraq', *Journal of University of Babylon for Engineering Sciences*, Vol. 29, No. 1, pp.44–52.

Ozdemir, F., Ar, I.M. and Baki, B. (2021) 'A decision model approach for determining social innovation potential of technological projects', *Journal of Multi-Criteria Decision Analysis*, Vol. 28, Nos. 1–2, pp.112–125.

Pang, N., Nan, M., Meng, Q. and Zhao, S. (2021) 'Selection of wind turbine based on fuzzy analytic network process: a case study in China', *Sustainability*, Vol. 13, No. 4, p.1792.

Pourmazaherian, M., Baqutayan, S.M.S. and Idrus, D. (2021) 'The role of the big five personality factors on accident: A case of accidents in construction industries', *Journal of Science, Technology and Innovation Policy*, Vol. 7, No. 1, pp.46–55.

Statistics, B.O.L. (2016) *Census of Fatal Occupational Injuries*, Bureau of Labor Statistics, Washington, DC.

Stephen, C. and Hunt, B. (2002) 'Safety management systems in Hong Kong: is there anything wrong with the implementation?', *Managerial Auditing Journal*, Vol. 17, No. 9, pp.588–592.

Sunindijo, R.Y. (2015) 'Improving safety among small organisations in the construction industry: key barriers and improvement strategies', *Procedia Engineering*, Vol. 125, pp.109–116.

Suresh, N. (2017) 'Fire safety management in construction', *DHARANA-Bhavan's International Journal of Business*, Vol. 8, No. 2, pp.80–83.

Yi, K-J. and Langford, D. (2006) 'Scheduling-based risk estimation and safety planning for construction projects', *Journal of Construction Engineering and Management*, Vol. 132, No. 6, pp.626–635.

Yiu, N.S., Chan, D.W., Shan, M. and Sze, N. (2019) 'Implementation of safety management system in managing construction projects: benefits and obstacles', *Safety Science*, Vol. 117, pp.23–32.

Yiu, N.S., Sze, N.N. and Chan, D.W. (2018) 'Implementation of safety management systems in Hong Kong construction industry – a safety practitioner's perspective', *Journal of Safety Research*, Vol. 64, No. 1, pp.1–9.

Zou, P.X. and Sunindijo, R.Y. (2015) *Strategic Safety Management in Construction and Engineering*, John Wiley and Sons, Hoboken, NJ, USA.