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Recognizing the effective factors in managing fire incidents to reduce the collateral damages and casualties

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Abstract

Purpose – The purpose of this study is to introduce and evaluate the effect of critical success factors (CSF) in rescue operations in burning buildings by calculating the partial least squares structural equation modeling of PLS-SEM.

Design/methodology/approach – To do this, success criteria (SC) and CSF in the literature, which are related to the topic, articles, standards and relevant books, will be identified and then evaluated through the extended PLS-SEM model.

Findings – The results show that technological factors, awareness, resources and safety play an effective role in successful performance management in fire accidents.

Research limitations/implications – Appropriate use of these factors will promote incident management and decrease casualties and financial loss in the event of accidents.

Originality/value – Fire-fighting is of great importance, especially in tall and complex buildings. In recent years, extended studies have been carried out regarding fire accident management in terms of CSFs in the category of rescue and firefighting. However, attention has not been paid to the relation and severity of impact between SC and CSF by researchers in addition to the identification of the most important criteria during rescue operations.

Keywords Evaluation, PLS-SEM, Fire safety, Criteria, On-the-job training, Hazard prevention in buildings

Paper type Research paper

Introduction

During the past 30 years, the perception of human behavior in fire incidents has changed from the default reaction of panic and irrational responses to constructive and cooperative decision-making (Kinsey *et al.*, 2019). The victims of fire accidents in buildings are on the increase compared to other natural disasters, despite significant improvements in architecture and construction engineering (Mirahadi *et al.*, 2019). A great deal of studies has been carried out to find effective management factors to minimize the number of injuries and victims worldwide. Wu and Chen (2012) suggested that the use of search algorithms, software simulation and route safety assessment are among the important factors in improving accident scene management. Shen *et al.* (2008) showed that having firefighting

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systems, firefighting equipment and environmental complexity are among the factors that improve incident scene management. Other factors considered in previous studies are the importance of structures, communication, artificial intelligence (AI) (Harris, 2013), emphasis on the importance of time and training (Kang *et al.*, 2016), on-time fire location identification (Chen *et al.*, 2018), central control system, digital devices, communication type, etc. (Davies *et al.*, 2009). Comprehensive knowledge of different factors may improve performance management success in the structured discharge plan (Mirahadi *et al.*, 2019). More research is needed on materials development, technologies and strategies that decrease the risk of loss and are repairable and replaceable in a cheaper, easier and faster way. Understanding the link between materials and technologies and making interactions between them is also required (Sattar *et al.*, 2018). Making use of technology in evacuation planning results in easier rescue operations. To avoids risk measures in emergencies, this planning must include analysis of technical maps, risk evaluation, recognition of preventive measures and targets available in the surroundings (García-Hernández *et al.*, 2019). Through combining agent-based model technical population simulation with fire simulation tools and creating informative models, we can form a frame for evacuation (Mirahadi *et al.*, 2019). In plan response to evacuation in emergencies, often many of the factors of critical success in safe evacuation are not used. Identifying more factors leads to increased safety in evacuation planning (Mirahadi *et al.*, 2019; Boguslawski *et al.*, 2016) and avoiding a reduction in the effectiveness of rescue forces, to prevent being confronted with casualties from the incident (Soltaninejad *et al.*, 2020). Effective incident management starts with good preparation (Vandecasteele *et al.*, 2017). In these types of incidents, the main challenge is assisting rescue forces in evacuation planning (Boguslawski *et al.*, 2016). A review of the literature indicates the importance of SFs in different studies. For example, the most important topics in this field include simulating, storing and integrating information (Mirahadi *et al.*, 2019; Chen *et al.*, 2018; Gharouni Jafari *et al.*, 2020; Gharouni Jafari *et al.*, 2021; Abbasi and Noorzai, 2021; Bakmohammadi and Noorzai, 2020), type of communication (Ohta and Dunkel, 2019) and use of graphical tools to facilitate rescue operations (García-Hernández *et al.*, 2019). It seems none of the studies conducted so far has a general definition of recognizing effective factors, relations and the effect of a factor on improving the critical success of evacuation planning. In this study, to investigate and understand the relationship and effect intensity between success criteria (SC) and critical success factors (CSFs), according to the factor analysis method, based on the intensity of correlation between variables, to simplify data analysis, data have been divided into different groups. To investigates the relationships between variables based on research theory, structured relationships according to partial least squares structural equation modeling (PLS-SEM) method as the second generation of SEM method have been used. The results show that by increasing identification of factors, incident performance management decreases mortality rates compared to traditional samples.

Literature review

The emergency response in the building environment has been extensively studied. After the September 11, 2001 attacks and increasing the importance of emergency reaction, many of the studies focused on escape and rescue based on indoor routes (Zverovich *et al.*, 2016). There is a need to research on developing cheaper, easier and faster technologies and strategies to reduce the likelihood of injury. This requires an understanding of the relation between different factors in an accident (Sattar *et al.*, 2018). Research has identified different factors as the reasons for casualties in fire accidents. For example, according to a study by Mirahadi *et al.* (2019), 19.8% of casualties are because of exit problems (population density, limited and locked outputs, mechanical barriers) and 16.8% due to escape problems (excessive distances, improper route selection and re-entry). Understanding human behavior in the event of an emergency is an important factor in designing safe evacuation systems, based on the SFPE standard (Helander, 2005). Review literature on fires in buildings indicates that studies in this regard can be divided into two main categories.

Identification, classification and evaluation of the success factors

Generally, based on the literature review of the subject of fire, CSF considered at the time of fire are divided into four main groups (technology, environmental knowledge, safety and resources) and two dependent subgroups (operationalized information of environmental knowledge [IK] and operationalized information of technology [IT]), based on the similarity between the factors. Given the complexities of human behaviors and fire in the emergency exit, many parameters are taken into account in simulating the evacuation. As a result, the simulation takes a lot of time. In simulating the building evacuation during an incident, two types of parameters, discrete (types of materials, special materials, ventilation situations, etc.) and continuous (location of the fire, heat transfer rate, population density, etc.) are examined (Yang *et al.*, 2013). According to Richardson *et al.* (2019), the factors of knowledge of building geometry, locations of individuals, smoke concentration and its effects, individuals' familiarity with the environment, identification of exit routes and alternate routes if necessary, communication between people, group guidance and command and readiness of people at the time of the incident are defined as SF success factors. In addition, according to Till and Coon (2018), other factors include appropriate tool detection, identification of fire phase based on the fire timeline, individuals training levels, indoor contents, smoke concentration, building alert system, notification time, gas type, simulated model importance, architecture barriers importance and fire temperature. García-Hernández *et al.* (2019) assessed the effectiveness of rescue operations using different graphical tools to help firefighters in the rescue operation. In this respect, they found that using aerial photos, 360° photos, dimensional photos and maps, virtual reality (VR) technology, video and updated information by firefighters can improve and decrease operation time. Chou *et al.* (2019) proposed using a uniform smart rescue system based on the real-time and simultaneous use of it with automatic sensors, communication systems, firefighting equipment, Bluetooth sensors, proper planning to rescue using search algorithms, individuals' location, etc., to improve rescue methods. According to Boguslawski *et al.* (2016), the destruction caused by incidents such as fire and explosion leads to fire or instability in the building structure. These calamities are rare but inevitable. The use of up-to-date information about the building, floor plans, exits, the different types of materials in the building and architectural obstacles can reduce the response time to emergencies. According to this research, in the evacuation planning of complex buildings, numerous factors such as the building plan, point of origin, residence area, safe area and exits, are considered as success factors in preparing and improving the aforementioned safe evacuation plan. According to Chou *et al.* (2019), in rescue operation planning, the complexity of a building, having a database of the building's information, avoiding mayhem through prioritizing the measures, etc., are considered important CSF in preparing and improving the aforementioned rescue operation plan. Precise locating in the building, being aware of the building's details, setting up a control center out of the building and identifying the energy sources are other success factors in critical success in preparing and improving the evacuation planning (Li *et al.*, 2014). Also, according to the model proposed by Vandecasteele *et al.* (2017), critical data are used for decision-making during an incident. Based on this model, factors such as quick decision-making, locating the point of origin, number and the location of casualties, the type of the building's structure, the type of the materials in the building, identifying evacuation paths, amount of heat, carbon monoxide density in the air, using technology and architectural obstacles in the building, are known as success factors in firefighting strategies during a fire incident. Also, according to a study conducted by Boguslawski *et al.* (2018), in evacuation planning of complex buildings, numerous factors such as the building's plan, point of origin, residence area, identifying the exits and human behaviors are known as success factors. Further, according to the model proposed by Averill (2011), using AI, we can evaluate the structure resistance which is one of the factors of preparing and improving the evacuation plan during a fire incident. A number of CSF in performing a successful evacuation, based on the comparison of the articles, is provided in Table 1.

Identification, classification and evaluation of the success criteria

Different criteria were recognized to improve event operation management based on literature review and to improve event operation management and decrease casualties and financial losses. according to (Boguslawski *et al.*, 2016; Vandecasteele *et al.*, 2017; Zverovich *et al.*, 2017) One of the recognized criterion for success in saving time, and therefore decreasing casualties is "upgrading and improving decision-making speed" during an emergency event. In addition, according to Kang *et al.* (2016), Rüppel and Schatz (2011), Chou *et al.* (2019), Noorzai and Golabchi (2020), Noorzai *et al.* (2020), Noorzai (2020), Gharouni Jafari *et al.* (2014) and Cocking *et al.* (2009) "safety" is an important factor in operation management improvement. According to research conducted by Kang *et al.* (2016), the principal reason for death is unsafe measures and unsafe conditions. Based on their research, lack of knowledge, safety awareness and unsafe practices are the main reason for death. According to (Mirahadi *et al.* (2019) study, one of the factors that should be taken into consideration in evacuation planning is the safe evacuation of residents. According to past studies (Xu *et al.*, 2018; Davies *et al.*, 2009; Cocking *et al.*, 2009), the factor of "coordination and connections" during an emergency event improves operation management. Different groups such as the police, firefighters, public health and volunteer organs should work as a group rather than individually to be able to share information and work together harmoniously (Bandyopadhyay and Mukherjee, 2016). The factor of "proper guide" is another factor in improving operational management (Osman and Ram, 2013; Groner *et al.*, 2012). Adequate management is significant at the scene of the event using the relevant rescue equipment and search personnel to provide a vital timely response and, in turn, decrease the damage potential during the occurrence (Zverovich *et al.*, 2017).

Research method

The popular methods for identifying and assessing success factors are statistical methods and surveys. Confirmation factor analysis (CFA) is proposed as a powerful tool to examine the problems in analyzing the research hypothesis factors. CFA and SEM as statistical methods can indicate the relationship between research variables (Akbari Ahmadabadi and Heravi, 2019b). There are two generations of SEM, namely, covariance-based SEM (CB-SEM) and PLS-SEM (Hair *et al.*, 2013). One of the challenging issues in using SEM is collecting data to validate the model. PLS-SEM, as the second generation, has decreased data abnormality effects and the number of data needed for the model validation. PLS-SEM analysis can easily cover an item structure. In contrast, covariance-based SEM (CB-SEM) often eliminates the related variables and cannot analyze the model criteria structures (Akbari Ahmadabadi and Heravi, 2019a). PLS-SEM is used in this research to assess CSF's effect on SC success and the route analysis.

Table 1. Reviewing past studies

Factor	Mirahadi *et al.* (2019)	Chou *et al.* (2019)	Li *et al.* (2014)	Ohta and Dunkel (2019)	Till and Coon (2018)	Boguslawski *et al.* (2016)	Chen, Liu and Wu (2018)	Richardson *et al.* (2019)	Vandecasteele *et al.* (2017)	Wu and Chen (2012)	Zverovich *et al.* (2016)	Wang *et al.* (2015)	Bandyopadhyay and Mukherjee (2016)
1			✓			✓	✓		✓				✓
2	✓			✓		✓	✓	✓		✓		✓	
3	✓						✓			✓	✓		
4	✓			✓									
5	✓				✓		✓	✓		✓		✓	
6					✓								
7		✓	✓			✓	✓					✓	
8		✓											
9					✓	✓			✓		✓		
10						✓			✓			✓	
11	✓		✓	✓			✓	✓					
12						✓	✓						

Notes: 1: location information; 2: building plan; 3: distance; 4: population density; 5: simulated models; 6: technical maps; 7: building database; 8: building complexity; 9: architecture barriers; 10: structure type; 11: familiarity with the environment; 12: locating exits and entrances

One of the significant challenges in this regard is the existence of sufficient data to model validation. One of the reasons for PLS popularity is that there is no need for a large number of samples (Boomsma and Hoogland, 2001). The serious limitation in using CB-SEM is the model sensitivity to non-normal data and a large number of input data. The accepted criteria in CB-SEM is 15 items in each measured variable or 10 items in each parameter with the least critical ratio of 5:1 (Hair *et al.*, 2012). The amount of required data is 150–200 in many studies which are not practical due to research limitations (Akbari Ahmadabadi and Heravi, 2019a; Gharouni Jafari and Noorzai, 2021). Smart PLS in the process of data analysis of the PLS method and the related software are designed in such a way to minimize the sensitivity to sample size. So the normality of data analysis is not a barrier in the use of PLS either (Davari and Rezazadeh, 2017). The present research method includes four steps (Figure 1):

(1) Gathering information and identifying SC and CSF criteria by reviewing the subject literature and experts' opinions;

(2) Developing a design structure matrix (DSM) model to determine the relationships between the articles and common criteria;

(3) Investigating the underlying hypotheses and relations between SC and CSFs by PLS-SEM model; and

(4) Examining the results and identifying the most important factors in fire accidents.

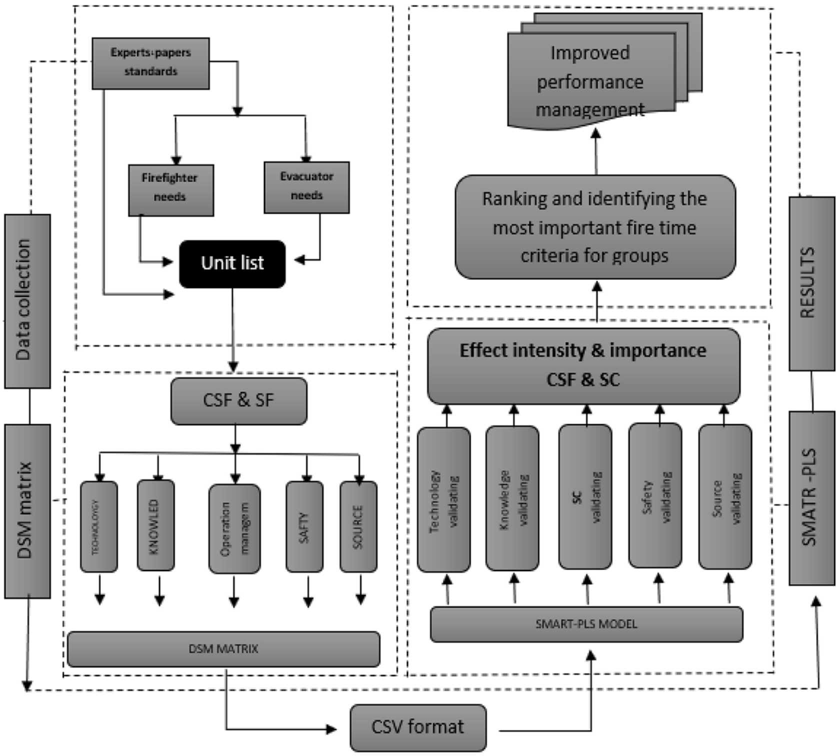

Figure 1.
Research method

Collecting data and identification of critical success factors and success criteria to assess literature review and the views of experts

The groups involved in the event are grouped into two main groups of firefighters and evacuees with individual aims. Different aims create diverse needs during an emergency event (Chen *et al.*, 2018). Four criteria are considered to assess operation management success during and post-event according to the subject literature Table 2. Accordingly, 26 SC were identified. The main point is that the implementation of PLS-SEM will weaken model proportion with a wide range of variables. So the variables number must be limited to reach a proper model (Tabish and Jha, 2012). Accordingly, the variables are divided into four main groups (technology, environmental knowledge, safety and source) and two dependent groups (technology operational information and environmental knowledge operational information) based on similarity. The variables are provided in Table 3.

DSM development

DSM is a tool to manage repeated activities based on parameters (Jacob and Varghese, 2011). To be sure, DSM is used as an operational tool appropriately to show commission, correlation and model parts relations. The main advantage of this method is that it overcomes network complexity. Furthermore, the model facilitates information updating (Akbari Ahmadabadi and Heravi, 2019a). DSM is used in this study due to complexity in control of the relations between criteria and the sample, to decrease complexity, difficulty in imagine and managing information. Table 4 shows the DSM model proposed in this research.

Assessing hypotheses and partial least squares-structural equation modeling model development based on the relations between critical success factor and success criteria

To validate the research hypothesis, the primary version of the questionnaire was first modified and completed by university professors and safety experts. The Gutmann criteria were used in this study. Accordingly, 155 persons, with at least a bachelor's degree, with a minimum age of 26 and at least 3 years of work experience were interviewed, out of whom,

MANAGEMENT	SC	Reference
	SC1: upgrade and improve decision speed	1; 2; 3; 5; 9; 10; 12; 20; 43; 45; 65
	SC2: safety management	2; 3; 6; 7; 8; 10; 12; 14; 17; 18; 19; 30; 35; 37; 38; 43; 48; 49; 54; 59; 60; 62; 65;
	SC3: strong communication and coordination	2; 5; 6; 8; 9; 10; 16; 14; 18; 19; 31; 42; 43; 48; 55; 61; 63
	SC4: correct guidance and guidance	1; 2; 3; 5; 9; 10; 12; 20; 43; 45; 65

Notes: 1: (Boguslawski *et al.*, 2016); 2: (Vandecasteele *et al.*, 2017); 3: (Li *et al.*, 2014); 5: (Cheng *et al.*, 2016); 6: (Wang *et al.*, 2015); 7: (Wu and Chen, 2012); 8: (Zverovich *et al.*, 2016); 9: (Zverovich *et al.*, 2017); 10: (Yang *et al.*, 2013); 12: (Osman and Ram, 2013); 14: (Hsu *et al.*, 2014); 17: (Sattar *et al.*, 2018); 18: (Shen *et al.*, 2008); 19: (Kang *et al.*, 2016); 20: (Groner *et al.*, 2012); 30: (Rüppel and Schatz, 2011); 31: (Cheng *et al.*, 2017); 35: ("SFPE_HumanBehavior_Guide_fir.pdf", no date); 37: (Iran National Regulatory Office, 2013); 38: (Emergency exit routes, 2003); 42: (García-Hernández *et al.*, 2019); 43: (Chou *et al.*, 2019); 45: (Evans *et al.*, 2019); 48: (National Fire Protection Association, 2007); 49: (Pope and Bailey, 2006); 54: (Boguslawski *et al.*, 2018); 55: (Xu *et al.*, 2018); 59: (Wagner and Agrawal, 2014); 60: (Cocking, Drury and Reicher, 2009); 61: (Davies *et al.*, 2009); 62: (Venkatesh *et al.*, 2019); 65: (Shi *et al.*, 2009)

Table 2. Performance management SC

Table 3.
CSF and SF

CSF	SF	refrence
Technology	SF6: identification, optimization and planning of route	1; 2; 3; 4; 5; 6; 7; 8; 9; 12; 14; 15; 16; 19; 22; 30; 31; 32; 35; 43; 47; 50; 52; 53; 54; 57; 63; 65
	SF7: informational arrangement	1; 2; 3; 5; 6; 8; 15; 17; 19; 27; 30; 31; 43; 44; 46; 52; 56; 58
	SF8: identifying the people involved in fire	1; 2; 3; 5; 7; 9; 31; 37; 38; 43; 47; 52; 53; 54; 56
	SF9: locating importance	1; 2; 7; 14; 22; 35; 44; 52; 54; 62
	SF10: supervision importance	1; 2; 4; 8; 14; 19; 20; 22; 46; 52; 61; 62; 63
	SF11: identifying the location of fire	1; 2; 5; 8; 10; 12; 14; 18; 24; 25; 39; 43; 48; 53; 54
	SF12: the importance of not interfering in groups activity	1; 2; 3; 4; 5; 6; 7; 8; 9; 12; 19; 22; 30; 31; 32; 35; 43; 47; 50; 52; 53; 54; 57; 63; 65
Knowledge	SF1: importance of simulated models	1; 2; 4; 5; 6; 7; 8; 9; 10; 12; 15; 16; 17; 18; 21; 23; 24; 28; 29; 30; 32; 35; 39; 41; 42; 47; 49; 50; 52; 53; 59; 60; 63; 64; 65
	SF2: architectural barriers identification	1; 2; 8; 16; 50; 52; 53; 54; 64; 65
	SF3: importance of building complexity	4; 5; 14; 18; 13; 48; 52; 53; 54; 64
	SF4: importance of locating exits and entrances	1; 6; 7; 8; 10; 12; 15; 16; 31; 37; 38; 39; 43; 47; 52; 54; 59
	SF5: population density	1; 2; 6; 10; 12; 14; 15; 32; 35; 53; 59; 60; 64
Safety	SF24: proper guidance and commands	2; 5; 12; 14; 19; 22; 31; 39; 43; 44; 48; 52
	SF25: alert system	2; 5; 8; 10; 12; 14; 19; 22; 26; 62; 64
	SF26: the concentration of smoke and its effects	2; 4; 5; 6; 7; 9; 10; 18; 21; 22; 25; 27; 29; 30; 31; 35; 39; 40; 43; 44; 52; 62; 64; 65
Source	SF21: the importance of time	1; 2; 3; 6; 7; 8; 9; 10; 12; 14; 15; 21; 22; 23; 25; 26; 35; 40; 42; 43; 49; 50; 53; 54; 56; 61; 62; 63; 65
	SF22: the importance of limited resources and access	1; 6; 16; 17; 25; 31; 43; 52; 54; 61
	SF23: scheduling operations based on time-limited resource	1; 2; 3; 6; 7; 8; 9; 10; 12; 14; 15; 21; 22; 23; 25; 26; 42; 43; 49; 50; 53; 54; 56; 61; 62; 63; 65
IT	SF17: operational tools and information	2; 4; 5; 6; 7; 8; 9; 12; 13; 14; 15; 16; 17; 22; 30; 31; 34; 37; 38; 42; 43; 46; 47; 49; 50; 52; 54; 55; 56; 58; 61; 62; 65
	SF18: information integration platform	1; 2; 3; 5; 6; 8; 13; 15; 17; 19; 27; 30; 31; 43; 44; 46; 52; 53; 54; 55; 56; 58
	SF19: incident management system	2; 5; 6; 8; 9; 10; 13; 14; 18; 19; 31; 42; 43; 48; 55; 61; 63
	SF20: digital tool as a guide	2; 4; 5; 6; 7; 8; 9; 12; 13; 14; 15; 16; 17; 22; 30; 31;33; 34; 37; 38; 42; 43; 46; 47; 49; 50; 52; 54; 55; 56; 58; 61; 62; 65
IK	SF13: knowledge of the design of the building and its environment	1; 2; 3; 5; 6; 8; 12; 15; 16; 17; 18; 19; 20; 22; 34; 35; 39; 40; 41; 43; 44; 46; 48; 50; 53; 54; 60
	SF14: operational guide	1; 2; 5; 6; 8; 9; 10; 12; 14; 16; 17; 18; 19; 37; 38; 42; 43; 48; 50; 53
	SF15: the importance of communication and coordination	1; 2; 7; 10; 13; 14; 22; 31; 43; 44; 45; 48; 61; 62
	SF16: importance of geometric design of buildings	1; 2; 3; 5; 6; 8; 12; 15; 16; 17; 18; 19; 20; 22; 34; 35; 39; 40; 41; 43; 44; 46; 48; 50; 53; 54; 60

(*continued*)

Table 3.

CSF	SF	refrence

Notes: 1: (Boguslawski *et al.*, 2016); 2: (Vandecasteele *et al.*, 2017); 3: (Li *et al.*, 2014); 4: (Olenick and Carpenter, 2003); 5: (Cheng *et al.*, 2016); 6: (Wang *et al.*, 2015); 7: (Wu and Chen, 2012); 8: (Zverovich *et al.*, 2016); 9: (Zverovich *et al.*, 2017); 10: (Yang *et al.*, 2013); 11: (Drysdale, 2011); 12: (Osman and Ram, 2013); 13: (Lurz *et al.*, 2017); 14: (Hsu *et al.*, 2014); 15: (Xu *et al.*, 2016); 16: (Isikdag *et al.*, 2013); 17: (Sattar *et al.*, 2018); 18: (Shen *et al.*, 2008); 19: (Kang *et al.*, 2016); 20: (Groner *et al.*, 2012); 21: (Shi *et al.*, 2009); 22: (Harris, 2013); 23: (Porcari *et al.*, 2015); 24: (Suwondo *et al.*, 2019); 25: (Mould, 2001); 26: (Knyziak *et al.*, 2019); 27: (Naser, 2019); 28: (Shan *et al.*, 2019); 29: (Yuen *et al.*, 2014); 30: (Rüppel and Schatz, 2011); 31: (Cheng *et al.*, 2018); 32: (Thompson and Marchant, 1995); 33: (Qiao *et al.*, 2012); 34:(Averill, 2011); 35: ("SFPE_HumanBehavior_Guide_fir.pdf", 2017); 36: (National Iranian Gas Company, 2013); 37: (Iran National Regulatory Office, 2013); 38: (Emergency exit routes, 2003); 39: (Richardson *et al.*, 2019); 40: (Till and Coon, 2018); 41: (Xie *et al.*, 2018); 42: (García-Hernández *et al.*, 2019); 43: (Chou *et al.*, 2019); 44: (Li *et al.*, 2014); 45: (Evans *et al.*, 2019); 46: (Bandyopadhyay and Mukherjee, 2016); 47: (Ohta and Dunkel, 2019); 48: (NFPA 1500, 2007); 49: (Pope and Bailey, 2006); 50: (Mirahadi *et al.*, 2019); 51: (Kinsey *et al.*, 2019); 52: (Chen *et al.*, 2018); 53: (Zhang and Issa, 2015); 54: (Boguslawski *et al.*, 2018); 55: (Xu *et al.*, 2018); 56: (Boje *et al.*, 2018); 57: (Smith and Brokaw, 2008); 58: (Park *et al.*, 2017); 59: (Wagner and Agrawal, 2014); 60: (Cocking *et al.*, 2009); 61: (Davies *et al.*, 2009); 62: (Venkatesh *et al.*, 2019); 63: (Fahy *et al.*, 2017);64: (Kasereka *et al.*, 2018); 65: (Shi *et al.*, 2009)

Table 4.
DSM model

Title	Sf																										SC			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	1	2	3	4
(Boguslawski *et al.*, 2016)	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			*	*	*	*			*	*		*	*
(Vandecasteele *et al.*, 2017)	*			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*
(Li *et al.*, 2014)						*	*	*				*	*			*	*			*	*		*			*	*	*		*
(Olenick and Carpenter, 2003)	*				*				*		*						*								*					
(Cheng *et al.*, 2016)	*				*	*	*			*	*	*	*		*	*	*	*	*				*	*	*	*			*	
(Wang *et al.*, 2015)			*	*		*	*					*	*	*		*	*	*	*	*	*		*			*		*		
(Wu and Chen, 2012)		*			*		*	*			*			*			*			*		*			*		*	*		
(Zverovich *et al.*, 2016)	*	*	*		*	*	*			*	*	*	*	*		*	*	*	*	*	*		*	*	*	*		*		
(Zverovich *et al.*, 2017)		*				*		*				*		*				*	*		*		*	*		*	*			*
(Yang *et al.*, 2013)		*	*							*			*	*				*		*		*		*		*	*	*	*	
(Drysdale, 2011)																	*													
(Osman and Ram, 2013)	*	*		*					*	*	*	*		*		*			*		*	*	*	*	*	*		*		
(Lurz *et al.*, 2017)															*		*	*	*	*									*	
(Hsu *et al.*, 2014)		*		*		*			*	*	*	*		*	*			*	*		*		*	*	*	*		*	*	
(Xu *et al.*, 2016)		*	*		*	*					*	*			*	*	*		*	*		*			*					
(Isikdag *et al.*, 2013)	*		*		*	*						*	*	*		*		*				*				*				
(Sattar *et al.*, 2018)							*						*	*		*	*	*		*		*						*		
(Shen *et al.*, 2008)	*									*		*	*		*			*									*			
(Kang *et al.*, 2016)						*	*			*		*	*	*		*	*		*	*				*	*	*		*		
(Groner *et al.*, 2012)									*			*			*											*			*	
(Shi *et al.*, 2017)																					*		*							
(Harris, 2013)					*			*	*		*	*		*	*		*			*		*	*	*	*			*		
(Porcari *et al.*, 2015)																		*		*										
(Suwondo *et al.*, 2019)										*																				
(Mould, 2001)									*										*	*	*									
(Knyziak *et al.*, 2019)																					*		*		*					
(Naser, 2019)							*										*			*										
(Shan *et al.*, 2019)																				*										
(Yuen *et al.*, 2014)																				*										
(Rüppel and Schatz, 2011)		*	*					*					*	*		*						*		*						
(Cheng *et al.*, 2018)		*			*	*	*				*			*		*	*	*	*		*		*		*			*		
(Thompson and Marchant, 1995)	*		*						*														*							
(Qiao *et al.*, 2012)																				*										

(continued)

Title	Sf																										SC			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	1	2	3	4
(Averill, 2011)													*			*		*												
SFPE				*		*			*			*	*		*	*					*		*			*		*	*	
(National Iranian Gas Company, 2013)																*														
Iran National Regulatory Office, 2013)	*					*						*				*										*				
(Emergency exit routes, 2003)			*					*						*				*										*		
(Richardson *et al.*, 2019)	*								*		*			*								*								
(Till and Coon, 2018);													*			*					*		*							
(Xie *et al.*, 2018)													*			*														
(García-Hernández *et al.*, 2019)										*				*	*		*		*											
(Chou *et al.*, 2019);	*	*			*	*	*			*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*	
(Li *et al.*, 2014)							*		*				*		*	*	*			*				*					*	
(Evans *et al.*, 2019)													*												*		*	*		
(Bandyopadhyay and Mukherjee, 2016)	*			*			*			*	*	*		*																
(Ohta and Dunkel, 2019)		*			*		*				*						*								*					
NFPA 1500, 2007		*									*		*	*	*	*			*					*				*	*	
(Pope and Bailey, 2006)																*			*		*					*				
(Mirahadi *et al.*, 2019)	*				*	*						*	*	*		*		*			*		*			*				
(Kinsey *et al.*, 2019)																				*										
(Chen *et al.*, 2018)	*	*	*		*	*	*	*	*	*		*					*	*		*		*		*		*				
(Zhang and Issa, 2015)	*	*			*	*		*			*	*	*	*		*	*			*	*		*			*				
(Boguslawski *et al.*, 2018)	*	*	*		*	*		*	*		*		*			*	*	*		*	*	*	*			*		*		
(Xu *et al.*, 2018)																	*	*	*	*										
(Boje *et al.*, 2018)					*	*									*	*		*	*		*									
(Smith and Brokaw, 2008)						*						*														*				
(Park *et al.*, 2017)							*										*	*		*										
(Wagner and Agrawal, 2014)	*	*																								*				
(Cocking *et al.*, 2009)			*									*			*												*			
(Davies *et al.*, 2009)									*					*			*	*		*	*	*						*		
(Venkatesh *et al.*, 2019);								*	*					*			*			*		*		*			*	*		
(Fahy *et al.*, 2017)				*				*		*							*		*		*			*						
(Kasereka *et al.*, 2018)	*	*		*	*																				*					
(Shi *et al.*, 2009)	*				*	*						*						*			*		*			*	*	*		*

Table 4.

25 left the study and gave no responses. Finally, 130 completed questionnaires were used in the validation of the PLS-SEM model, among whom, 20 were university professors, 50 worked in construction, 26 were safety engineers and 34 were firefighters. Among the participants, 15.38% were the PhD professors of the university, with at least 7 years of experience. Also, 23.07% were construction engineers, worked in the field of building and structure with a BS degree and at least 3 years of experience. Further, 9.32% of respondents held a master's degree and had at least 6 years of experience while 6.15% were PhD graduates with at least 20 years of experience. In addition, 12.07% of participants were experts working in the field of safety engineering with a bachelor's degree and at least 7 years of experience and 7.69% with a master's degree had at least 10 years of experience. Finally, 26.15% of the participants were firefighters with a bachelor's degree and at least 4 years of experience. The relevant data are provided in Table 5 and Figure 3. One of the

Table 5.
Characteristics of the respondents

Job	Number	Degree	Work experience	Age	(%)
University professors	20	PhD	More than 7 year	more than 38	15.38
Worked in construction	30	Bachelor	More than 3 year	26 < age < 35	23.07
	12	Master	6 < experience < 20	26 < age < 43	9.32
	8	PhD	More than 20 year	age > 43	6.15
Safety engineers	16	Bachelor	More than 7 year	30 < age < 36	12.07
	10	Master	More than 10 year	35 < age < 42	7.69
Firefighters	34	Bachelor	More than 4 year	26 < age < 32	26.15

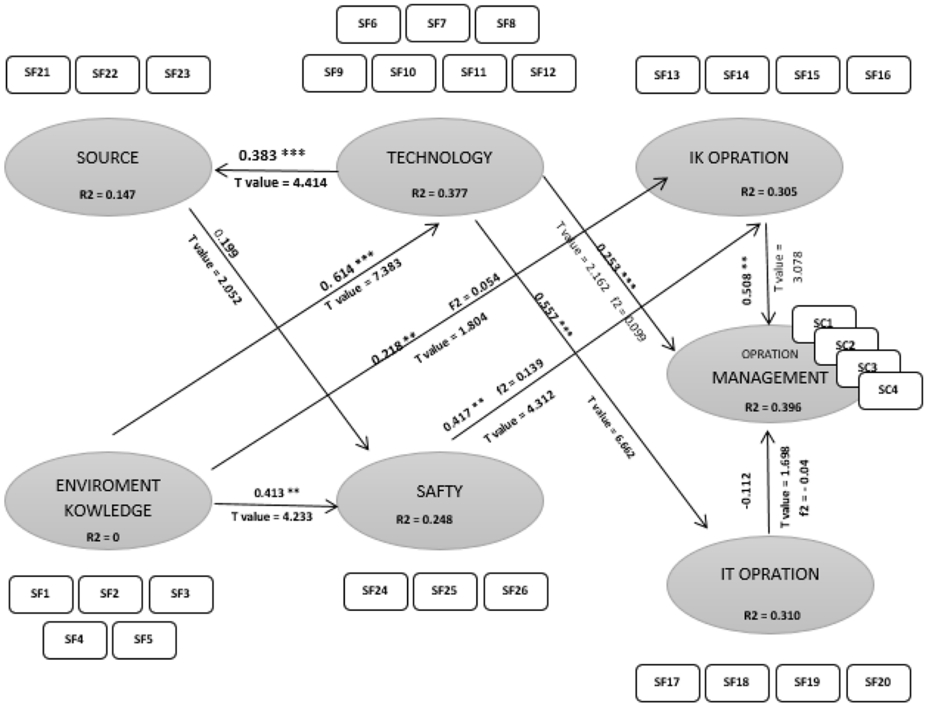

Figure 2.
Smart-PLS model

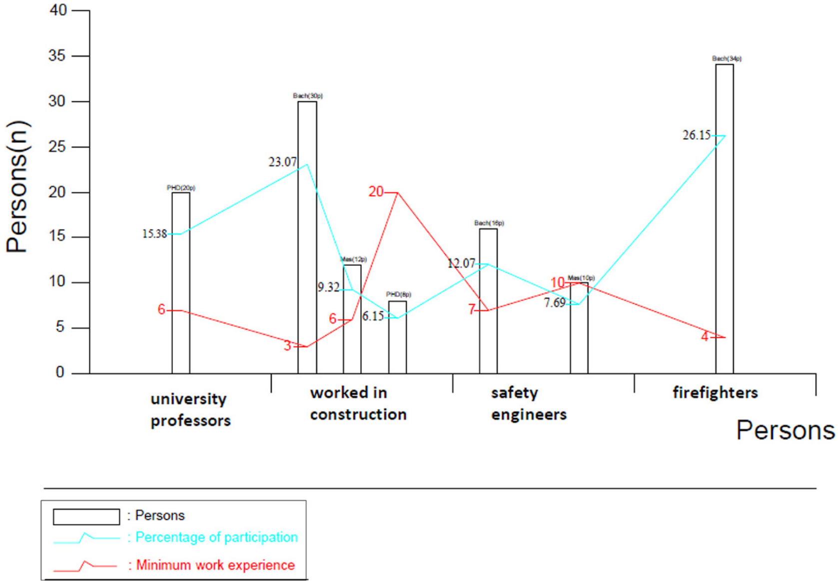

Figure 3. Characteristics of research participants

challenging subjects in the study is collecting enough data to validate the model. One of the serious limitations to using CB-SEM is the sensitivity of the model to the normality of input data and its amount. PLS-SEM has decreased the effect of data normality and the number of required data to validate the model according to the dimensions of the proposed model (Akbari Ahmadabadi and Heravi, 2019b). The number of required samples is estimated as 10 times more than the following criteria using the rule of thumb (Barclay *et al.*, 1995).

The sample needed to measure hypotheses is equal to 70 samples, based on the provided hypotheses including the relations between latent and apparent variables. Although the rule of thumb with 10 items is the most common way to identify the minimum sample size, it is incorrect (Kock and Hadaya, 2018; Akbari Ahmadabadi and Heravi, 2019b).

Model validation and obtained results

To validate the proposed model, factor load must be more than 0.4, composite reliability values should be more than 0.7 and Cronbach's alpha values must be greater than 0.7. Based on Moss *et al.*, the limit of Cronbach's alpha coefficient is 0.6 regarding variables with few questions (Moss *et al.*, 1998). The proposed model has obtained the needed quorum for validation. Also, the mean values of the AVE variance should be greater than 0.5 (Akbari Ahmadabadi and Heravi, 2019b). According to Davari and Rezazadah (2017), the minimum AVE can be considered as 0.4. Based on the results provided in Table 6, the proposed model has a quadratic limit value of extracted variance (Davari and Rezazadeh, 2017). In addition, the AVE square root of any latent structure must exceed the internal structure correlation (Akbari Ahmadabadi and Heravi, 2019b), which is confirmed by the results obtained from the model shown in Table 7.

To examine the accuracy of the relationship between structures and to confirm the research hypotheses between structures in the model (structural part), the path coefficient values of z or the same t-values are used. The numbers t only represent the correctness of the relationships and the intensity of the relationship cannot be measured according to them. In

Criteria	SF	Factor loading	AVE	CR	Cronbach's alpha
Knowledge			0.439126	0.786337	0.653349
	SF1	0.848			
	SF2	0.573			
	SF3	0.555			
	SF4	0.424			
	SF5	0.812			
Technology			0.401186	0.814313	0.729139
	SF6	0.848			
	SF7	0.518			
	SF8	0.637			
	SF9	0.554			
	SF10	0.428			
	SF11	0.456			
	SF12	0.846			
IK			0.496309	0.794428	0.665602
	SF13	0.773			
	SF14	0.711			
	SF15	0.533			
	SF16	0.773			
IT			0.523199	0.808131	0.672548
	SF17	0.884			
	SF18	0.598			
	SF19	0.535			
	SF20	0.816			
Source			0.692721	0.859871	0.743425
	SF21	0.975			
	SF22	0.434			
	SF23	0.962			
Safety			0.557556	0.789533	0.60896
	SF24	0.81			
	SF25	0.654			
	SF26	0.767			
Management			0.497943	0.795072	0.654806
	SC1	0.779			
	SC2	0.543			
	SC3	0.662			
	SC4	0.807			

Table 6.
Model validation data output

the final step of model development, the path coefficient value was calculated using the bootstrapping method to assess the validity of the model hypotheses. According to Akbari Ahmadabadi and Heravi (2019b), the values considered acceptable for the (*t*) value are three values of 2.58, 1.96 and 1.65, which specify strong to weak (*t*) values. Also, Hair *et al.* (2011) suggested that acceptable *t*-values for a two-tailed test are 1.65 (significance level = 10%), 1.96 (significance level = 5%) and 2.58 (significance level = 1%). This value must be greater than 1.96 to confirm the calculated values (Davari and Rezazadeh, 2017). Accordingly, all plotted routes are approved. In addition, R^2 coefficients and F^2 effect size are used to assess the structural model. The R^2 value corresponds to the endogenous (dependent) hidden variables of the model. Accordingly, this value indicates the effect of an exogenous variable on an endogenous variable. In addition, three values of 0.19, 0.33, 0.67 are considered for the weak, medium and strong values of the R^2 coefficient (Davari and Rezazadeh, 2017). According to the plotted PLS-SEM model Figure 2, the calculations indicate an approved effect of exogenous on the endogenous variables. It should be noted that R^2 values depend on the model complexity and the high value of R^2 shows proper anticipation of the values through the PLS route. The values should be effectively high to have minimum descriptive power for the model (Akbari Ahmadabadi and Heravi, 2019b). F^2 index was used to find the effect of a structure on the other structure which is one of the criteria for fitting the structural model of the proposed model. Accordingly, three values of 0.02, 0.15 and 0.35 show the low, moderate and high effect of a structure on the other structure. Totally, R^2 and F^2 indicate the structural model validation, showing that the structure can be used as a prediction tool in the project.

The R^2 value in performance management equals 0.39%, which shows the strength of the overall structural model fit and the acceptable impact of hidden structures (technology, operational knowledge of environmental knowledge and operational information of technology) on performance management, based on the results of the model Figure 2. Also, the strength (R^2 = 0.377) in technology shows the high impact of environmental knowledge on the successful use of technology in the fire. In addition, the strength (R^2 = 0.305) calculated of the operational knowledge of environmental knowledge, we can find the impact of safety information and environmental knowledge on this variable. The value (F^2 = 0.054) calculated in the model shows the impact of using environmental knowledge to make operational knowledge at the time of the accident. The calculated impact factor also shows the impact of using technology (F^2 = 0.099) on incident performance management. Based on these calculations (F^2 = 0.139) the proper effect of safety information on operational information obtained from environmental knowledge is seen.

Results

The data gathered from the PLS-SEM statistical population was examined and the results are explained in the following:

The effective management of accidents requires high readiness. According to firefighting studies to reduce mortality, it is important to identify the factors that reduce mortality at the time of the accident. Studies have so far introduced various factors as effective on reducing accident mortality. However, none of the studies has comprehensively identified the effective factors to reduce mortality in the most complex situations with the possibility of

Variable	IK operating	IT operating	Knowledge	Operation management	Safety	Source	Technology
IK operating	1						
IT operating	0.374111	1					
Knowledge	0.40952	0.299146	1				
Operation management	0.599072	0.218864	0.220266	1			
Safety	0.517305	0.413473	0.459425	0.434716	1		
Source	0.288642	0.1343	0.61426	0.332947	0.294672	1	
Technology	0.523895	0.55678	0.577637	0.456946	0.794628	0.382992	1

Table 7. Latent variable correlations

interfering with the activities of different groups involved in the accident. In addition to the intensity of the effect, the relationship between factors is not clear. In this study, in addition to comprehensive identification of factors affecting the reduction in mortality at the time of the accident, the relationship between factors and the intensity of their effect on the success of managing rescue operation performance, and thus mortality has been addressed. The R^2 value in performance management equals 0.39%, which shows the validity of the overall structural model fit and the acceptable impact of hidden structures (technology, operational knowledge of environmental knowledge and operational information of technology) on performance management, based on the results of the model Figure 2. According to the results obtained in Figure 2, the criteria identified in different groups including technology, environmental knowledge, resources and safety as independent groups and operational information derived from environmental knowledge and operational information obtained from technology as dependent groups based on the validity of the model are effective on improving the success of performance management. The use of the factor technology (SF6-SF12) directly and based on the production operational information obtained from technology (SF17-SF20) indirectly had a great effect on the success of performance management. Increasing the level of environmental knowledge such as information (SF1-SF5) to produce technology (SF6-SF12) and safety (SF24-SF26) indicators played a direct role and through operational information production (SF13-SF16) played an indirect role in performance management success.

Discussion

According to the results, population simulation models and the importance of population density in response to evacuation play an effective role in the success of performance management. According to Till and Coon (2018) simulated models help to understand what we are going to encounter at the scene of an accident. A framework for building evacuation can be created by integrating agent base population simulation techniques with fire simulation tools and developing information models (Mirahadi *et al.*, 2019). Also, planning and optimizing the path without interfering with the activities of different groups has a great impact on the technology benchmark. According to the model presented by Chou *et al.* (2019), to find the optimal path at the time of the accident, routing algorithms has been used by considering various factors such as fire speed, internal characteristics of the building and distance from the fire scene. The factor of time as a non-renewable resource at the time of the accident is one of the most important sources for the success of performance management, which is of particular importance. Research on building evacuation optimization has considered the factor of time as an important decision factor for the success of evacuation (Boje *et al.*, 2018). The use of routing networks at the time of the accident is used to reduce storage costs for reducing computation time (Boguslawski *et al.*, 2016). According to Vandecasteele *et al.* (2017), the factor of guiding and leading evacuation groups while preventing the interference of the activities of different groups increases the speed of operations and saves the accident time. Guiding and leading different groups at the time of the accident to evacuate and control operations using different information has been introduced as an important and effective factor in performance management of different groups and time optimization. The availability of different information about the structure and internal geometry is essential for simulating the movement of people and finding exits for people of different groups (Boguslawski *et al.*, 2016). According to the findings of the research (Figure 2), using technology and its operational information in planning the building evacuation, based on the reduced time taken for setting up communication, understanding the information and updating the information at the moment play an effective role in the critical success of performance management during an incident. The mentioned criteria were of great importance such as the study by Boguslawski *et al.* (2016) when finding proper routes using navigation is not possible and sufficient while the ability to rescue and finding alternate routes by rescuers is imperative. Accessibility of information about interior structures to simulate people's movement and find a route for them and other different groups is of great importance. According to Boje *et al.* (2018) using technology increases the group's ability to find a route and making use of important information. The current status of using digital technology for the structure life cycle is permanently developing. A proper level of automation is needed to use large and multimedia data and the capability of cooperation in different subjects. Also, according to the findings of the research (Figure 2), informative knowledge of engineering plan and architectural obstacles, facilities in the building, knowledge about the paths' capacity and correct guidance play an effective role in producing information, to improve the critical success of the performance management. Chen *et al.* (2018) claimed that having no knowledge of the current condition during a fire is the most important reason for relief forces mortality. Regarding Boguslawski *et al.* (2016), knowledge of accessibility conditions as the first response during emergency situations is of great importance. Knowledge related to the interior geometry status of the structure and the firefighting equipment location pre-entrance to the structure will promote repose to the emergency situation. In fire accidents, due to the lack of structural and environmental information at the time of the accident, people avoid moving in the exit routes and prefer to use firefighting equipment, which reduces safety, and thus increases casualties (Osman and Ram, 2013). Also, the analysis of the information (Figure 2) shows that increasing awareness toward the environment's safety and increasing local knowledge are effective in the correct guidance and lead to the betterment of the performance management and increased level of safety for the other groups involved in the incident. Proper guidance and command have the greatest impact on safety factors and prompt performance of forces and increases safety during accidents (Chou *et al.*, 2019). In buildings with accident management systems, required information to exit can be obtained rapidly and precisely and people can be guided to the exits and, in turn, it decreases mortality and loss (Cheng *et al.*, 2016). The direct reason for death is the unsafe actions and unsafe conditions of the materials. Ignorance of safe conditions of the operation surroundings increases the risk and danger for the rescue forces (Kang *et al.*, 2016). Based on the analysis of research results (Figure 2), resource management and planning (time, materials and manpower) increase safety, and thus improves performance management at the time of the accident. It takes a lot of time to get out of the building due to lack of sufficient information about the fire and its configuration, incorrect choice of the correct exit route and lack of awareness of changes and related ambiguity (Chen *et al.*, 2018). Firefighting is not successful in all fire accidents. For this reason, evacuation strategies and building safety regulations are primarily based on the evacuation time (Mirahadi *et al.*, 2019). Lack of accurate planning for the evacuation of people and rescue forces increases movement disorders and consequently increases evacuation time. Vandecasteele *et al.* (2017) stated that one of the critical data in evacuation planning is the knowledge of the type of materials and resources available in terms of heat resistance, fire and heat conduction. Also, according to the research results (Figure 2), the use of technology plays an effective role in optimizing the use of available resources at the time of the accident. It is possible to reduce time delay at the time of accidents using digital versions of maps and creating a communication platform (Chou *et al.*, 2019). Based on the model proposed by the García-Hernández *et al.* (2019), digital tools were used to browse guides, maps, as well as increase access speed and personal protection (García-Hernández *et al.*, 2019).

Conclusion

The relation between CSFs and their impact on operation management during accidents was studied precisely. The factors were classified with respect to their wide range. SC were classified in the SC group. The aim of this study was to find the relation and effect severity between SC and CSFs and identify the most important criteria during rescue operations in fire accidents. To do so, a model was proposed to assess factors. The obtained results show model accuracy and its ability to anticipate the effect of the factors. The factor of technology has a great effect on operation management success. The factor of environmental knowledge affects technology and safety and also in creating operational knowledge and improves operation management. The factor of safety is affected by two factors of resources and environmental knowledge and helps to create operation information and ultimately improves operation management. In addition, snowball sampling was used instead of probable sampling.

In this study, in addition to comprehensive identification of factors affecting the casualty reduction at the time of an accident, the relationship between factors and the intensity of their effect on the success of managing rescue operation performance has been investigated. The results provide useful insights into the important factors for an optimal building evacuation plan at the time of an accident. Today, the design of such a plan is based on fixed factors, faced with high uncertainty due to different and special conditions of each accident and performing calculations manually. Accurate information about the accident situation, appropriate decisions based on comprehensive factors and careful monitoring are very important in the success of accident management. Future research can play a very important role in reducing casualties in fire accidents by optimizing evacuation based on identified comprehensive factors and combining it with VR and augmented reality (AR) technologies.

One of the limitations of this research was the use of a self-report questionnaire which has been used to measure the oncoming research hypotheses. It is possible that the responses were influenced by the level of participation, motivation and level of education of the individuals. Creating a general framework for success in the performance of the discharge program requires full knowledge of the current and past conditions of the structure and the eternity of this information based on the changes made and its application to the model created from the past to the present. Recommended factors can be used to create a smart safe discharge framework, the creation of the accident scene control software platforms and safety design.

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