Investigation of Factors Influencing the Implementation of Smart Fire Management using the Fuzzy Approach in Yazd, Iran

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Date of submission: 05 Apr. 2020 *Date of acceptance: 24 Nov. 2020*

Original Article

Abstract

INTRODUCTION: The development and application of new firefighting technologies are inevitable considering an increase in the number of smart technologies, the widespread use of technologies in various industries and all domains of human societies, utilization of polymeric materials in the tools and infrastructure of societies, as well as the production of new structures with diverse uses, and their aggregation together. The occurrence of massive disasters due to the lack of development and application of safety along with technology is the result of neglecting safety in the development process and social progress. This study aimed to investigate the factors influencing the implementation of smart fire management using the fuzzy approach.

METHODS: This descriptive-analytical study was designed based on an applied research method. Initially, all factors influencing the implementation of smart fire management were extracted from the literature. They were then evaluated based on experts and university professors' opinions. Following that, three types of questionnaires were distributed among the experts. The study population included 15 university experts and managers in the Fire Organization in Yazd, Iran.

FINDINGS: The results showed that "command and operations", "integration of smart firefighting systems", "clear business plan and vision", "effective change management", "equipment", "cooperation between the business association and information technology" and "management support" obtained positive D-R and were considered causes.

CONCLUSION: The "integration of smart firefighting systems" was regarded as the most effective factor, followed by "organizational resource planning", "exchange system", and "communication system" that ensure the success of these systems. This improves information flow and decision-making process, especially in a crisis.

Keywords: AHP; DEMATEL; Fire station; Fuzzy Approach; Smart Management; Yazd.

How to cite this article: Sayadi Tooranloo H, Mirghafouri SH, Hamifar M, Ayatollah AS. **Investigation of Factors Influencing the Implementation of Smart Fire Management using the Fuzzy Approach in Yazd, Iran.** Sci J Rescue Relief 2020; 12(3): 197-209.

Introduction

Fire organizations are among the centers that play a vital role in ensuring the safety of citizens during emergencies. The smartization of urban safety and firefighting services to respond to accidents is an effective step in reducing hazards. Regarding the implementation and development of smartization of the firefighting services, there are challenges, such as the lack of specialized manpower to take advantage of novel technologies in organizations in charge of safety and firefighting in Iran. Intelligent management should be comprehensive; otherwise, it not only fails to achieve safety in the

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[DOI: 10.32592/jorar.2020.12.3.5]

general sense but also will incur heavy expenses on the society in the long run.

Urban life along with the comfort and well-being provided for urban dwellers has many hazards and events that threaten the lives and properties of individuals. Humans have always been interested in dealing with these hazards and attempted to avoid these events as much as possible. In this regard, the role of fire organizations in ensuring the safety of cities and villages should be taken into account. Fire stations are among the service and emergency elements that have a vital role in protecting the lives and properties of people against different accidents, especially fires. Moreover, fire stations hold the responsibility of ensuring safety in the city against fire hazards in various domains, as well as the life and financial security of citizens (1).

Annually, many minor and tragic accidents, including fires, building collapses, accidents, earthquakes, and floods occur in different parts of Iran, which is accompanied by a lot of financial and human losses. Moreover, thousands of people get injured and many get homeless. Furthermore, accidents caused by new technological advances threaten human lives. As it is reported, despite the significant reduction in disease-related mortality rates and advances in personal and public health, humans are now losing most of their lives during natural disasters and accidents, such as car accidents, plane crashes, and environmental pollution (2).

The utilization and update of management strategies, technology, and smartization have always been one of the approaches to increase the security of services and facilities. It is of significant importance to have access to new equipment and technologies in society in order to make use of new technologies and develop activities related to safety and firefighting. Furthermore, there is a need for education, protocols, and standards, as well as new knowledge and novel sciences to employ new technologies and benefit from them at the community level (3).

In this regard, conventional systems can be replaced with intelligent addressable fire alarm systems due to their numerous capabilities. The development and application of new firefighting technologies are inevitable considering an increase in the number of intelligent technologies, widespread use of these technologies in various industries and all domains of human societies, use of polymeric materials in the tools and infrastructure of societies, as well as production of new structures with diverse uses and their aggregation together.

Several studies that have been conducted in this regard include smartization of the relief process and operations in the fire department to improve urban safety (4), investigation of the importance of safety, urban, and firefighting smartization (3), crisis management in high-rise building fire operations using the Intelligent Alarm System and the location of rescuers and the injured (5), a cloud platform for smart firefighting facilities maintenance based on the Internet of Things (6), smart fire warning system (7), and intelligent emergency response system for dangerous fire threats using the Internet of Things (8).

The occurrence of massive disasters due to the lack of development and application of safety along with technology is the result of neglecting safety in the development process and social progress, followed by the incident of numerous accidents with a wide range of damages in different societies. Accordingly, a significant relationship can be observed between fatal accidents in societies and their speed of development. With this background in mind, this study aimed to investigate the factors influencing the implementation of smart fire management using the fuzzy approach.

Mousavi et al. (2017) conducted a study entitled "Smartization of the relief and operation process in the fire department to improve urban safety (a case study of intelligent accident management in District 4 of Rasht Municipality). They highlight that smart cities provide infrastructures required by citizens, service providers, and governments to make intelligent decisions. The cities utilize new technologies to collect data, such as satellite images and integrate them with field surveys, as well as rescue and relief statistics from field studies in fire organizations. Therefore, the aforementioned study employed a novel approach to integrate satellite data and information with field surveys, statistics, and operational reports, followed by data analysis through a location-based tool to make the relief and operation process smart. This phenomenological study aimed to explain the management method of dealing with risks in a smart manner to achieve and improve urban

[DOI: 10.32592/jorar.2020.12.3.5]

safety. In this regard, they conducted a case study on District 4 in Rasht, Iran (4).

Motahhari and Rezazadeh (2016) investigated the importance of smartization of safety, cities, and fire stations". They emphasized the lack of suitable conditions for the active presence of the private sector in order to develop education on public safety and firefighting, as well as inefficient laboratories in the field of fire, safety, and firefighting equipment in Iran.

Attention to the smartization of the safety of the city should be comprehensive; otherwise, it not only fails to achieve the safety conditions but also will incur heavy expenses on the society in the long run. Therefore, it is of significant importance to pay more attention to the safety of citizens, especially safety against fire accidents, in the smartization of safety projects in urban areas (3).

Similarly, Zeidabadi (2016) performed a study entitled "Crisis management in high-rise building fire operations using the Intelligent Alarm System and the location of rescuers and the injured". This study subsequently discussed the application of this system in fire organizations and other relief organizations and proposed solutions for solving some problems (5).

In the same line, Pirmoradi (2009) conducted a study entitled "Determination of the best location to plan for new fire stations using information technology and Spatial Information System (GIS)". This study aimed to determine the best locations and the best place to reconstruct a fire station (a case study in one of the zones in District 6 in Tehran) using GIS and Analytic Hierarchy Process (AHP).

This study initially assessed the factors required in locating fire stations using 1: 2000 maps of District 6 in Tehran, Iran. Subsequently, the maps of factors were prepared and reclassified based on the required factors in locating fire stations. Following that, each factor was weighted using the pairwise comparison method, which is part of the AHP method. According to the prepared model, the factor maps were compiled using the combined index and the appropriate areas were identified. Eventually, the best place to construct a fire station was determined using the AHP (14).

A study entitled "A cloud platform for smart firefighting facilities maintenance based on the Internet of Things" was carried out by Guan et al. in 2018. This study proposed a cloud platform to maintain and repair firefighting facilities based on the Internet of Things. Moreover, it provided cloud computing to achieve a focus, maintain, manage, and design fighting facilities in a smart manner. This platform mainly consists of three subsystems. The results showed improvements in the maintenance of firefighting equipment using this platform (15).

Alismaili and Ali (2016) conducted a study entitled "Intelligent Fire Alarm System". This study was conducted on existing security systems, and the system was designed and implemented according to its restrictions. One version of the system was implemented and assessed under different conditions. According to the results, the proposed intelligent firefighting system accurately detected the onset of fire and responded quickly and reliably. The system reliability index was estimated at 93%, which was within an acceptable range (16).

Similarly, Phaneendra et al. (2018) conducted a study entitled "Intelligent emergency response system for dangerous fire threats using the internet of things". This study proposed an emergency response system for fire hazards using a standard IO structure. Accordingly, a fire detection sensor, a smoke detection sensor (MQ-5), a flammable gas detection sensor, and a GPS module were used to implement this scheme.

The sensors detected the hazards and alerted local emergency organizations, such as fire and police stations by sending the emergency to the service through which everyone is connected. Eventually, an integrated intelligent system using the Internet of Things was designed and presented in this study (17). In the same vein, Liu et al. (2001) conducted a study entitled "Development of fire detection systems in smart buildings". This study investigated the current state of development of fire alarm and alarm systems in smart buildings.

New technologies and concepts developed in smart buildings, such as advanced multi-purpose sensors, computer vision systems, wireless sensors, Real-Time Internet control, and integrated building service systems, were also discussed in this study. These new technologies and concepts increase the system's fire detection capability to distinguish between fire and non-fire threats, as well as the time available to protect peoples' lives and properties (18).

Methods

This descriptive-analytical study was designed based on a practical approach to analyzing the factors affecting the implementation of smart fire management using scientific sources, information obtained from the study sample, and multi-criteria decision-making methods (AHP and DEMATEL) in the fuzzy environment. The study population included all managers and experts in the field of smart firefighting. Considering the limited number of experts in this field and the specialty of the subject, the study included 15 experts from the University of Science and Art, as well as managers from the Fire Organization, Yazd, Iran.

Initially, all factors affecting the implementation of smart fire management were extracted from the relevant literature. Subsequently, these factors were reviewed, modified, and sometimes removed or added according to the experts' and professors' comments. Furthermore, the content validity of the items was confirmed in this study. Following that, three types of questionnaires were distributed among experts in order to collect data. The first questionnaire aimed to identify and reach a consensus on the factors affecting the implementation of smart fire management. In addition, the second questionnaire was used to determine the importance of the identified factors, and the relationships among the factors were assessed using the third questionnaire. The research procedure consists of three phases as follows.

Phase 1-Identification of the factors according to the literature, similar studies, and experts' comments

Initially, some previously conducted studies were identified by searching for keywords in domestic and foreign scientific databases, such as Science Direct, Emerald, SID, and Magiran. In the next stage, duplicate or inappropriate studies were excluded from the study. The remaining articles, as well as experts' and managers' comments, were utilized to extract the factors affecting the implementation of smart fire management (Table 1).

Table 1. Factors affecting the implementation of smart fire management

Factors	Items	Reference
Cooperation between the business association and information technology	Cooperation between the company's stakeholders and the IT department Combination of firefighting strategies with smart management strategies Coordination/cooperation between the employees of the fire department and the information technology department	(19-24)
Management support	Prioritization of the fire department smart management programs for senior managers Special support policies for the smartization of the fire department Managers effort to encourage employees to implement smart programs of the fire department Awareness of senior managers about the extent to which the fire department needs smartization Prioritization of the fire station needs for smartization Presence of a center to control and supervise smart projects of the fire department Information monitoring programs of the fire department	(21-29)
Data and system quality	Up-to-dateness, accuracy, precision, and completeness of data Comprehensibility and interpretation of data Effective and efficient distribution of information at the organization level High-quality nature of the fire department system Utilization of security levels to maintain information security System response speed Up-to-dateness of the software used	(24, 27, 30-34)
Precise definition of problems and business process	Awareness about the risks associated with implementing a smart management system Determination of factors to measure the risks associated with the smartization of the fire department Utilization of information technology in simplifying organizational processes	(24, 33-37)

Table 1. Continued

[DOI: 10.32592/jorar.2020.12.3.5]

Education and user support	Employees' access to educational courses Implementation of high-quality educational courses regarding the smartization of the fire department Utilization of strategies to encourage employee innovation and creativity	(21, 24, 34, 37-39)
Effective change management	Creation of motives among the employees as transformational role players Quick response to changes Spontaneous commitment of those interested in work through dialogue Intervention mechanisms to remove barriers Utilization of a reliable dataset in the fire department	(19,24, 26, 34, 37, 40)
Plan development and clear vision for future business	A clear vision for the use of smart systems in the fire department Coordination and cooperation between the overall vision of the organization and the vision of smart business Determination of smart programs to move from the current situation to the desired situation	(23, 24, 28, 29, 41)
Integration of smart firefighting systems	Automation degree of the key processes in the organization Coordination degree among units involved in the organization's processes	(21, 24, 29, 41, 42)
Commands and operations	Preparation of the SOP instructions and holding the necessary educational courses Creation and completion of appropriate operational charts and hierarchies related to smart management Smart documentation and assessment of incidents to address deficiencies Preparation of smart hazard and risk maps of the area in terms of construction, gas pipes, and hazardous materials storage Utilization of smart systems, such as GIS to accelerate, process, and deliver the information Smartization of the fire stations	Internal organizational documents and expert opinion
Equipment and facilities	Implementation of provisions to purchase comfortable and smart individual equipment Implementation of provisions to purchase smart rescue equipment for high-rise buildings, such as rescue tunnels, elevators, and ladders Installation of smart information and location systems, such as GPS on operational vehicles Smartization of finding the exact address via the caller's mobile or phone Strengthening the communication system (wireless, telephone) Replacement of worn-out automobiles with new and smart ones Holding weekly maneuvers and periodic exercises using smart equipment	Internal organizational documents and expert opinion

Phase 2. Weighting of factors using the fuzzy AHP technique

In this phase, the fuzzy AHP technique proposed by Buckley (1985) was used to determine the weighting of the factors. Table 2 tabulates the triangular fuzzy numbers used in this technique.

The steps used in the Fuzzy AHP technique are as follows (Buckley, 1985):

Table 2. Verbal phrases and triangular fuzzy numbers

Verbal phrases	Fuzzy numbers
Preference is absolutely equal	(1,1,1)
Preference is almost equal	(0.5,1,1.5)
Preference is low	(1,1.5,2)
Preference is high	(1.5,2,2.5)
Preference is too high	(2,2.5,3)
Preference is absolutely high	(2.5,3,3.5)

Step 1 - Research Hierarchy Tree

The research hierarchy tree is drawn in this step based on the criteria and sub-criteria identified in the first phase.

Step 2 - Preparation of a pairwise comparison matrix

The pairwise comparison matrix is designed in this step based on the research hierarchy tree. Following that, the pairwise comparison of the hierarchical tree levels will be made based on the experts' opinions. Verbal phrases and fuzzy numbers in Table (2) are used to make pairwise comparisons.

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n2} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \dfrac{1}{\tilde{a}_{21}} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \dfrac{1}{\tilde{a}_{n2}} & \dfrac{1}{\tilde{a}_{n2}} & \cdots & 1 \end{bmatrix} \quad (1)$$

[DOI: 10.32592/jorar.2020.12.3.5]

Step 3 - Compatibility of the pairwise comparison matrix

Suppose $A=[a_{ij}]$ is the reciprocal positive matrix and $\tilde{A}=[\tilde{a}_{ij}]$ is the reciprocal positive fuzzy matrix. Now if $A=[a_{ij}]$ is compatible, then $\tilde{A}=[\tilde{a}_{ij}]$ can also be compatible. To calculate the compatibility of the pairwise comparison matrix, fuzzy numbers are converted to definite numbers. Following that, the rate of incompatibility is calculated for the finite matrix of pairwise comparisons.

Step 4 - Geometric mean of pairwise comparisons of experts

The geometric mean of pairwise comparisons of experts is obtained using Equation (2) (43).

$$\tilde{a}_{ij}=\left(\tilde{a}_{ij}^{1}\otimes\tilde{a}_{ij}^{2}\otimes\cdots\otimes\tilde{a}_{ij}^{n}\right)^{\frac{1}{n}} \qquad (2)$$

Step 5 - Calculation of Fuzzy Weights

The fuzzy weight of each index is obtained from Equation (3), in which *n* presents the number of experts, *j* signifies the number of indices, and *m* is the fuzzy number.

$$\begin{aligned}\tilde{w}_{j}&=\tilde{a}_{j}\otimes(\tilde{a}_{1}\oplus\tilde{a}_{2}\oplus\ldots\oplus\tilde{a}_{n})^{-1}\quad j=1,2,\ldots,n\\ \tilde{a}_{j}&=\left(\tilde{a}_{m1}^{1}\oplus\tilde{a}_{m2}^{2}\oplus\cdots\tilde{a}_{mn}^{n}\right)^{-1}\end{aligned} \qquad (3)$$

Step 6- Normalization of the obtained weights

Equation (4) is used to normalize triangular fuzzy weights (44).

$$W_{j}=\frac{a+b+c}{3} \qquad (4)$$

Phase 3- Relationship of factors with fuzzy DEMATEL technique

Fontela and Gabos first introduced the DEMATEL technique in 1976. This technique is one of the decision-making methods based on pairwise comparisons (45), which determines the interrelationships among criteria, as well as their impact, and importance as a numerical score. The most important feature of this method is its multi-criteria decision making process and the creation of relationships and structure among criteria.

This technique transforms the cause-and-effect relationships into a structural-visual model; moreover, it can identify the internal dependencies between factors and make them understandable. However, it is very difficult to transform the opinion of experts with accurate numerical values, especially in uncertain conditions since the outcome of decision-making is highly dependent on inaccurate and vague subjective judgments. This led to a need for fuzzy logic in DEMATEL (46). As a result, the fuzzy DEMATEL technique and triangular fuzzy linguistic variables have been used in this study. The steps are as follows:

Step 7- Initial direct-relation matrix (A)

The questionnaire related to the level of penetration of each index to other indices is prepared and distributed among the experts. After collecting the opinions of experts using Table (3), the verbal data are converted into fuzzy numbers, and the direct-relation matrix is determined using Equation (5).

$$A_{ij}=\frac{1}{H}\sum_{k=1}^{H}x_{ij}^{k} \qquad (5)$$

Step 8- Normalization of the initial direct-relation matrix (D)

The initial direct-relation matrix is obtained using Equations (6) and (7).

$$D=\frac{A}{S} \qquad (6)$$

$$S=\max\left(\max_{1\le i\le n}\sum_{j=1}^{n}A_{ij},\max_{1\le i\le n}\sum_{i=1}^{n}A_{ij}\right) \qquad (7)$$

Step 9- Creation of the $Z=[Z_x]$ matrix

Matrix Z_x is created using Equation (8) where $x=(a,b,c)$.

$$Z_x=\begin{bmatrix}0 & x_{12} & \cdots & x_{1n}\\ x_{21} & 0 & \cdots & x_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ x_{n1} & x_{n2} & \cdots & 0\end{bmatrix} \qquad (8)$$

Table 3. Verbal phrases and corresponding triangular fuzzy numbers (47)

Verbal Phrases	Fuzzy Number
No influence	(1,1,1)
Very low influence	(2,3,4)
Low influence	(4,5,6)
High influence	(6,7,8)
Very high influence	(8,9,9)

In total, three matrices are obtained from this matrix whose objects are non-fuzzy numbers. Matrix D is written in the form of three matrices to facilitate the calculations in the next step. It is worth mentioning that the number of rows in the $Z=[Z_x]$ matrix is equal to the number of columns in the matrix D.

Step 10- Determination of the total relation matrix (T_x)

The total relation matrix of all indices is obtained using Equation (9) in which I is the identity matrix.

$$T_x = Z_x(I - Z_x)^{-1} \tag{9}$$

Step 11- Analysis of causal relationships

The values of rows and columns are obtained to analyze the causal relationships. Equations (10-12) are utilized to determine the values of fuzzy $D+R$ and $D-R$.

$$T_X = \left[t_{ij}\right]_{m\times n} \qquad i,j = 1,2,\dots,n \tag{10}$$

$$D = r_X = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1 = [t_i]n\times 1} \tag{11}$$

$$R = c_X = \left[\sum_{j=1}^{n} t_{ij}\right]_{1\times n = [t_i]1\times n} \tag{12}$$

Step 12 -Calculation of the definite values $E(w)$

Regarding the fuzzy values of $D-R$ and $D+R$ obtained in the previous step, the definite values are obtained using the centre of gravity method according to Equation (13) where *a, b, c* are the objects related to fuzzy values of $D+R$ and $D-R$.

$$E(w) = \frac{a+b+c}{3} \tag{13}$$

Step 13 - Combination of fuzzy weights and $E(w)$

The fuzzy weights obtained from step six of phase 2 are multiplied by $E(w)$ values for each index to obtain new values using Equation (14).

$$E(W)_{new} = w_j \otimes E(W) \tag{14}$$

Step 14- A causal diagram

A causal diagram of all the indices is drawn in this step.

Findings

The results obtained from the steps presented in the previous section are presented as follows:

Phase 1 and 2

After reviewing the literature along with similar studies and conducting interviews with 15 university experts and managers of the Fire Organization in Yazd, Iran, the items influencing the implementation of smart fire management were classified into 10 main factors. Following that, a fuzzy AHP questionnaire was designed and distributed among the experts. In the next stage, a pairwise comparison matrix was formed after drawing a hierarchical tree. Furthermore, verbal phrases and fuzzy numbers listed in Table (2) were used considering the fuzzy approach applied in this study. Afterward, the compatibility of the pairwise comparison matrix was assessed using the Gogus and Butcher methods. Subsequently, the geometric mean of the pairwise comparisons of experts was calculated and normalized in this study (Table 4).

Table 4. Geometric mean of the pairwise comparisons and the normalized values

Factors	Geometrical mean	Normalized geometrical mean
C_1	(0.891,1.145,1.348)	(0.361,0.567,0.826)
C_2	(0.742,0.874,1.122)	(0.3,0.433,0.687)
C_3	(0.795,1.059,1.415)	(0.045, 0.081, 0.146)
C_4	(0.738,1.003,1.378)	(0.042, 0.077,0.142)
C_5	(0.669, 0.898,1.227)	(0.038,0.069, 0.127)
C_6	(0.783, 1.041, 1.387)	(0.045, 0.08,0.143)
C_7	(0.758,1.048,1.394)	(0.043, 0.08,0.144)
C_8	(0.707,0.965,1.26)	(0.04, 0.074,0.13)
C_9	(0.795,1.059,1.415)	(0.045, 0.081, 0.146)
C_{10}	(0.771,1.024,1.338)	(0.361, 0.567,0.826)

[DOI: 10.32592/jorar.2020.12.3.5]

Table 5. Final weight matrix of factors influencing the implementation of smart fire management

	Factors	Fuzzy final weighs	Final definite weighs
C_1	Cooperation between the business and information technology associations	(0.005,0.018,0.068)	0.027
C_2	Management support	(0.005,0.016,0.061)	0.023
C_3	Data and system quality	(0.005, 0.019,0.069)	0.028
C_4	Appropriate definition of business problems and processes	(0.005, 0.019,0.069)	0.027
C_5	User education and support	(0.005, 0.017,0.062)	0.026
C_6	Effective change management	(0.006,0.019,0.07)	0.028
C_7	Clear business plan and vision	(0.005,0.018,0.066)	0.027
C_8	Integration of smart firefighting systems	(0.006,0.02,0.076)	0.031
C_9	Command and operations	(0.005, 0.02,0.077)	0.031
C_{10}	Equipment	(0.005, 0.017,0.062)	0.025

In the last step of this phase, the fuzzy weights were initially calculated, and the obtained weights were then defuzzyfied based on Equation (4). After these calculations, the final weights were obtained as described in Table (5).

As can be seen in Table 5, among the identified factors, "integration of smart firefighting systems" and "command and operation systems" obtain the highest definite weights (0.31). Following that, there are "effective change management", "clear business plan and vision", "data and system quality", "precise definition of business problems and processes", "cooperation between the business and IT community", "user education and support", "equipment", and "management support" in descending order.

Phase 3- Determination of the relationship among the factors using the fuzzy DEMTAL technique

After determining the importance of the factors, the causal relationship among them was obtained using the fuzzy DEMTAL method. A questionnaire related to the effect of each of the 10 main factors on the other was prepared and distributed among experts. After collecting the experts' opinions, the verbal data were changed to fuzzy numbers using Table (3). Subsequently, the aggregation matrix of the experts' opinions (Table 6) was determined using Equation (5) as follows.

In the next step, the normalized initial direct-relation matrix was obtained using Equations (6) and (7) as described in Table (7).

After constructing the Z matrix using Equation (8), the total relation matrix was obtained using Equation (9). This matrix is shown in Table (8).

In the next steps, the sum of the values of the rows and columns were obtained to analyze the causal relationships, and Equations (10-12) were used to determine the values of fuzzy $D+R$ and $D-R$. These values were then determined based on Equation (13). In the last step, the obtained weights from the AHP method in the previous phase were multiplied by the determined values $E(w)$, and the new values were obtained using Equation (14). Table 9 summarizes the results of these calculations.

The casual relationships in Table 9 are illustrated in Figure 1.

According to Figure (1), "command and

Table 6. Aggregation matrix of the experts' opinion

Factors	C_1	C_2	…	C_{10}
C_1	(0.000,0.000,0.000)	(6.667,7.667,8.333)	…	(8.000,9.000,9.000)
C_2	(3.333,3.667,3.667)	(0.000,0.000,0.000)	…	(4.000,5.000,5.667)
C_3	(1.000,1.000,1.000)	(2.000,3.000,4.000)	…	(2.000,3.000,4.000)
C_4	(4.667, 5.667,6.333)	(4.667, 5.667,6.333)	…	(2.000,3.000,4.000)
C_5	(4.667, 5.667,6.333)	(4.000,5.000,5.667)	…	(4.667, 5.667,6.333)
C_6	(4.000,5.000,6.000)	(4.000,5.000,5.667)	…	(4.667, 5.667,6.667)
C_7	(2.000,3.000,4.000)	(4.000,5.000,6.000)	…	(6.000,7.000,7.667)
C_8	(5.333,6.333,7.000)	(5.333,6.333,7.000)	…	(5.333,6.333,7.333)
C_9	(6.667,7.667,8.333)	(4.000,5.000,6.000)	…	(6.000,7.000,7.667)
C_{10}	(7.333,8.333,8.667)	(3.333,4.333,5.333)	…	(0.000,0.000,0.000)

[DOI: 10.32592/jorar.2020.12.3.5]

Table 7. Normalized matrix

Factors	C_1	C_2	…	C_{10}
C_1	(0.000,0.000,0.000)	(0.038, 0.044, 0.048)	…	(0.045, 0.052, 0.052)
C_2	(0.019, 0.021, 0.021)	(0.000,0.000,0.000)	…	(0.023, 0.029, 0.033)
C_3	(0.006, 0.006,0.006)	(0.012, 0.017, 0.023)	…	(0.012, 0.017, 0.023)
C_4	(0.027, 0.033, 0.037)	(0.027, 0.033, 0.037)	…	(0.012, 0.017, 0.023)
C_5	(0.027, 0.033, 0.037)	(0.023, 0.029, 0.033)	…	(0.027, 0.033, 0.037)
C_6	(0.023, 0.029, 0.035)	(0.023, 0.029, 0.033)	…	(0.027, 0.033,0.038)
C_7	(0.012, 0.017, 0.023)	(0.023, 0.029, 0.035)	…	(0.035, 0.040, 0.044)
C_8	(0.031, 0.037, 0.040)	(0.031, 0.037, 0.040)	…	(0.031, 0.037, 0.042)
C_9	(0.038, 0.044, 0.048)	(0.023, 0.029, 0.035)	…	(0.035, 0.040, 0.044)
C_{10}	(0.042, 0.048, 0.050)	(0.019, 0.025, 0.031)	…	(0.000, 0.000, 0.000)

Table 8. Total relation matrix

Factors	C_1	C_2	…	C_{10}
C_1	(0.050, 0.112, 0.248)	(0.091, 0.163, 0.316)	…	(0.108,0.188,0.349)
C_2	(0.063, 0.121, 0.248)	(0.044, 0.100,0.230)	…	(0.078, 0.151, 0.306)
C_3	(0.029, 0.066,0.162)	(0.036, 0.081, 0.191)	…	(0.041, 0.091,0.210)
C_4	(0.059,0.112, 0.230)	(0.061, 0.118, 0.246)	…	(0.053, 0.117, 0.258)
C_5	(0.066, 0.125, 0.256)	(0.056, 0.129, 0.271)	…	(0.077, 0.148, 0.301)
C_6	(0.067, 0.131, 0.275)	(0.070, 0.138, 0.294)	…	(0.083, 0.159, 0.328)
C_7	(0.059, 0.125, 0.270)	(0.073, 0.144, 0.302)	…	(0.093, 0.172, 0.340)
C_8	(0.076, 0.141, 0.288)	(0.079, 0.149, 0.309)	…	(0.089, 0.166, 0.341)
C_9	(0.086, 0.153, 0.297)	(0.074, 0.146, 0.306)	…	(0.095, 0.175, 0.345)
C_{10}	(0.087, 0.152, 0.290)	(0.068, 0.138, 0.293)	…	(0.059, 0.131, 0.291)

Table 9. Importance and effect of the influential factors on the implementation of smart firefighting management

Factors	$(D_i - R_i)$	$(D_i + R_i)$	weights obtained from the APH	$(D_i - R_i)_{New}$	$(D_i + R_i)_{New}$
Cooperation between the business and information technology community	0.965333	8.192333	0.027	0.026064	0.221193
Management support	0.498333	7.784333	0.023	0.011462	0.17904
Data and system quality	-2.21233	7.49	0.028	-0.06195	0.20972
Precise definition of business problems and processes	-1.01167	7.866333	0.027	-0.02732	0.212391
User education and support	-0.55733	8.454667	0.026	-0.01449	0.219821
Effective change management	0.329667	8.343667	0.028	0/009231	0.233623
Clear business plan and vision	0.053667	8.939667	0.027	0.001449	0.241371
Integration of smart firefighting systems	1.131333	7.821	0.031	0.035071	0.242451
Commands and operation systems	0.085667	9.053667	0.031	0.002656	0.280664
Equipment	0.448	8.369	0.025	0.0112	0.209225

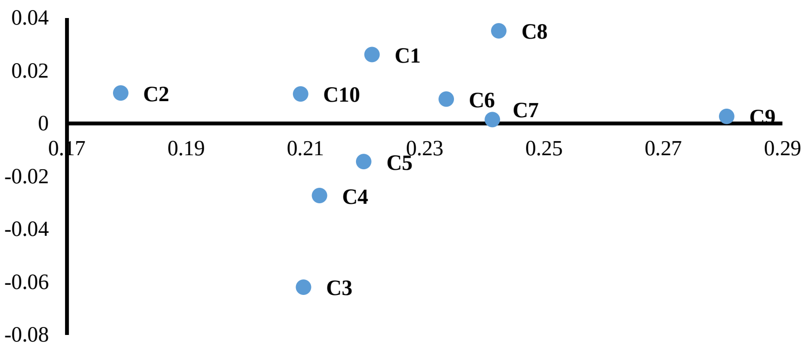

Figure 1. Casual relationships of factors influencing the implementation of smart firefighting management

[DOI: 10.32592/jorar.2020.12.3.5]

operation", "integration of smart firefighting systems", "data and system quality", "effective change management", "equipment", "cooperation between the business and information technology community", and "management support" obtain positive $D-R$ and considered causes. These factors act as the cornerstone of other factors and provide the basis for the implementation of other factors. Moreover, "clear business plan and vision", "precise definition of business problems and processes", and "user education and support" obtain negative $D-R$ and were regarded as effects. These factors are superstructure components that originate from the underlying factors.

Discussion and Conclusion

The majority of the environmental damage and instability in development are the consequences of urbanization and industrial development. As a result, urban centers are regarded as the most important influential targets for sustainable development. With the development of technologies and communication systems, all tools, machines, as well as application and management systems take steps forward to be smart. The utilization of intelligent management in urban systems and services leads to much wider and larger savings. Transportation and intelligent traffic control, use of spatial information, use of smart materials, banking and online sales, virtual office websites, electronic learning, distance healthcare, remote security, and safety control are among the elements that are becoming more developed and common.

Accordingly, it is necessary to have physical and qualitative control over the safety of cities in an intelligent manner along with changes in attitudes toward urban design with the use of new systems. One of these systems is the safety and security control system by firefighters which is becoming more and more advanced and developed. Fire stations are among the service-emergency elements in cities that have an important and vital role in protecting the lives and properties of people against numerous events, especially fires. Moreover, they are responsible for ensuring safety in the city against fire hazards, as well as the life and properties of citizens (48).

There has been much attention to the issue of smartization of safety in urban planning in recent years. Today, numerous and famous scientific associations, including the International Association of Urban and Regional Planners, are conducting studies on smartization of urban safety. The development and application of new firefighting technologies are inevitable considering an increase in the number of smart technologies, widespread use of these technologies in various industries and all domains of human societies, utilization of polymeric materials in the tools and infrastructure of societies, as well as production of new structures with diverse uses and their aggregation together. Therefore, smartization of urban safety and firefighting is of special importance that requires more attention. Accordingly, the present study aimed to evaluate the factors affecting the implementation of smart fire management using the fuzzy approach. Initially, all factors affecting the implementation of smart fire management were extracted from the relevant literature. Following that, these criteria were examined according to experts' and university professors' opinions. Subsequently, three types of questionnaires were distributed in order to collect data.

The final factors were identified according to the results of the first questionnaire. In the next stage, the experts' opinions were collected on the importance of each factor using the second questionnaire. Eventually, the third questionnaire was distributed to extract data related to the associations among the factors. After the determination of the factors, in the second phase of this study, the weights of criteria were determined using the fuzzy AHP technique. Following that, in the third phase, the relationship among the factors was determined using the fuzzy DEMATEL technique. The results indicated that "command and operations", "integration of smart firefighting systems", "clear business plan and vision", "effective change management", "equipment", "cooperation between the business association and information technology", and "management support" obtained a positive $D-R$ and were regarded as causes. These factors act as the cornerstone of other factors and provide the basis for the implementation of other factors.

Integration of smart firefighting systems with other systems, including resource planning, as well as exchange and communication systems ensures their performance success. This improves the information flow and the decision-making process, especially in a crisis. In fact, the integration of systems includes the degree of coordination among the units involved in the organization and the extent of automation of key processes in the organization (24).

Integrated smart systems utilize hardware and software required for integrated monitoring and control. Moreover, these systems monitor continuously and collect data of air conditioning system, lighting control, traffic control, fire alarm, extinguishing system, and video surveillance systems in order to provide an environment to react appropriately to the conditions based on the user instructions.

In this regard, the effective factors include the improvement of cooperation among units involved in the organization's processes, an increase in the degree of automation of key processes to integrate them with smart firefighting systems, as well as identify and assess risks associated with the implementation of this system to facilitate the implementation of smart firefighting management. Among other influencing factors, "clear business plan and vision" was considered one of the most effective elements in this regard.

This factor includes the presence of a clear vision for the use of smart systems in the fire department, coordination between the organization's overall vision and the business smart vision, and determination of smart plans required to achieve the desired condition. Accordingly, it is of critical importance to employ a long-term and strategic vision in order to implement the organization's smart systems since long-term visions are essential to directing efforts towards successful implementation. Moreover, organizations should be aware of their present status, provide the right definition of what they desire, and determine their goals, as well as the approaches employed to achieve them.

Experts and policymakers in organizations should design the organization's strategies based on surviving in difficult conditions so that the organization can achieve success in its performance. This finding is consistent with the results of studies conducted by Imhaf (2004), Watson (2004), as well as Kronios and Yeo (2010) (50, 49, 19). According to the results of this study, "data and system quality", "precise definition of problems and business processes", and user education and support" obtained negative $D-R$ and considered the effects. These factors are superstructure components that originate from the underlying factors.

It is worth mentioning that making decisions based on inaccurate and poor-quality data is a risky procedure. Accordingly, the "data and system quality" was considered one of the most influential factors in this study. In other words, the high quality of the data and systems used in the organization leads to the making of more reliable reports that can be delivered to senior managers so that they can use them in the decision-making process. Furthermore, acquisition of correct and timely information results in the improvement of decision-making quality (31, 24). The results also revealed that the "precise definition of problems and business processes" was among the most influential factor after "data and system quality". This factor includes the extent of knowledge of the risks associated with the implementation of the smart management system, determination of criteria to measure the risks associated with smartization of fire stations, and use of information technology in the implementation of organizational processes.

The measures that should be taken to implement smart projects include the preparation of a formal document mentioning the problems and requirements of the organization, involvement of other systems and individuals, time frame, assumptions, risks, and events.

Acknowledgments

The authors express their gratitude to all those who contributed to conducting this study.

Conflict of Interests

The authors have no conflict of interest to declare.

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[DOI: 10.32592/jorar.2020.12.3.5]