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ORIGINAL ARTICLE

Quantitative Analysis on Time Delay Factors Influencing Firefighters' Response Time in the Process Industries Using Fuzzy Sets Theory

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ABSTRACT

Response time management is one of the most critical issues for firefighting organizations in the process industries. Thus, in emergency response success, it is of particular importance to apply an appropriate method to identify, prioritize, and manage factors influencing response time. The current study aimed to determine factors affecting firefighters' response time in Iranian process industries. Therefore, firstly a Hierarchical Task Analysis (HTA) was performed for firefighting emergency response-related activities. Then, time influencing factors for each task were determined. Finally, we chose the importance of each influencing factor and its priority based on the Fuzzy Chang approach. The results showed that factors, including the proper location of the firefighting truck, wearing and adjusting the breathing apparatus (BA) strap, and crowded at the scene had a significant impact on the response time to fire alarms. The related weights were equal to 0.049, 0.0485, and 0.0481, respectively. On the contrary, the wrong size of protective ensembles, BA weight, and height of car chassis factors were not significant in the response time. Their weight was equal to 0.0003, 0.002, and 0.0073, respectively. The results showed that the Fuzzy Hierarchical Task Analysis Approach (FHTA) could be used to identify and prioritize the factors influencing firefighting response time.

KEYWORDS: *Emergency Response Time, Process Industries, Alarm Assignment, FHTA, Safety Management*

INTRODUCTION

Fire and explosion incidences in industrial environments cost companies and governments billions of dollars each year [1]. According to the latest statistics from the National Fire Protection Association (NFPA), 37,000 fires occur in industrial and manufacturing every year, with an average number of 16 civilians death, 273 injuries, and 1.2 billion dollars of financial losses [2-4]. The results of previous reports showed that about 40 percent of major industrial accidents were related to fires in Iran [5]. It was also found that about 15 percent of fatalities in oil and gas industries were related to fires and explosions, with the highest number of fatalities following traffic (% 41) and technical accidents (% 26)[6].

Many managerial and technical approaches have been suggested to minimize such severe incidents' occurrence and reduce their potential consequences. Therefore, preventive approaches and emergency response arrangements were utilized to mitigate the incident consequences. Generally speaking, the purpose of the emergency response is to save lives and minimize damages to property and infrastructures [7-10]. One of the most critical principles in emergency response quality and effectiveness is the response time [11, 12]. Firefighting response time refers to the time between an emergency call being received and a fire engine arriving at the incident scene. This time is a very important factor in preventing the severity of the consequences. Zarei et al. showed that if the response time of firefighters took more than 5 minutes, the probability of domino effects increases dramatically [13].

It can be addressed due to the time-depended nature of the emergencies and the importance of the golden time requirement where the primary purpose of the emergency responders and services is the prompt and efficient mobilization of firefighters in response to a fire or other related incidents [14, 15]. The emergency response concept can be identified by resources, systems, and personnel [16].

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Among those factors, the system aspects, including scheduling, task analysis, and so on, might strengthen personnel and operation efficiency in case of emergency incidents [7]. Studies have shown a logarithmic relationship between the number of fire damages and the rapid response of firefighters [17]. A slight delay in the dispatch process can lead to serious injuries. Thus, there would be severe consequences if there were no prompt intervention of firefighters [18-20].

Therefore, decreasing the response time and improving fire safety measures can significantly reduce potential fire damage. Next to that, various standards were set to measure firefighting response times performance [21] and internal best practices adopted by own organizations. For instance, NFPA 1710 suggests 4 minutes arrival time for 90% of municipal firefighting units [22]. However, there are operation standards and scenario differences between the industrial firefighting units and other sectors. Therefore, pre-incident planning should observe these time criteria and reduce the actual performances [17, 23, 24]. Due to the inherent characteristic of flame spread for the majority of the hydrocarbon products, swift responses are critical for industrial firefighting operations. On the other hand, complex and unplanned conditions at the incident scene might increase the overall incident control time [25, 26]. Therefore, one key to efficient response is decreasing the response time as much as possible [27].

In the previous studies, the researchers investigated emergency response time importance [16, 28-31], the relationship between the response time and the amount of damage and losses [17, 32-34], as well as the simulation of emergencies response times [11, 35]. All studies have found a strong relationship between the response time and the amount of fire damage.

Cabral et al. in their systematic review investigated the response time concepts in the emergency medical services response time. They discussed factors that interfere with the response time, such as the Gross Domestic Product (GDP) percentage spent on health and life expectancy of countries. They found that higher medical and health quality levels might reduce the response time for emergency medical services [36]. Through survival data analysis, Yeboah perused the influence of tree factors of highway-railway grade crossings, fire equipment allocation, and multiple incident occurrences in a fire district on the emergency response time. He demonstrated the benefits of having a grade crossing monitoring system and reallocation of fire engines with special features to improve emergency response time (37). Challands et al. investigated the monetary benefit of rapid emergency response with respect to the desired outcomes. So, they found the impact of proper communication technologies in response time improvement [38].

In a study conducted by Lu et al., they investigated the relationship between response time and fire-affected areas. So, it was found that the fire control ability becomes poor with longer fire attendance time [17]. Sund et al. also assessed the relationship between the dual dispatch technique and survival rates related to Emergency Medical Services (EMS) and fire departments. The results of their study showed great financial benefits for dual dispatch of emergency teams [33]. In another study, Jaldell et al. investigated the relationship between response time and injury rates. They concluded that the total monetary values for one minute of time-saving for each dispatch, summarized over one year, were 1.6 billion Thai baht [34]. Moreover, a direct relationship between response time and fire casualty by considering the type of accident place was found. They showed that the response time was crucial for blocks of flats, nursing homes, and semi-detached/terraced houses [16]. Aleisa et al. used a simulation approach to reduce the response time in their study. They successfully were able to reduce the average response from 7.3 minutes to around 3 minutes [11]. Subramaniam et al. measured the various response times for firefighters to get to the fire truck from the waiting room in selected fire stations in Malaysia. They concluded that the average initial emergency response implemented by firefighting units in Malaysia was better than that reported by previous studies by other emergency responders [7]. Tezavella et al. used Volunteered Geographic Information (VGI) and open-source data in an ArcGIS environment to reduce the emergency response time. They reported that VGI might decrease the emergency response time [39].

Despite the previous studies about the emergency medical response time, simulation and measurement, subsequent consequences, and impressible factors, there is a lack of studies to investigate influencing factors in the industrial environment response time. However, technical approaches such as the fuzzy technique to reduce uncertainty would be useful to reduce uncertainty in assessing and managing safety and emergency management [40-45]. Therefore, we aimed to identify factors influencing firefighters' response time through a Fuzzy approach.

MATERIALS AND METHODS

The current study follows a three steps procedures as presented in Figure 1.

Firefighting task analysis:

In the first step, we selected 20 firefighters to participate in the study as the expert panel, including firetruck drivers, dispatchers, managers, and field firefighters. Demographic information of the experts has been demonstrated in the Appendix. Two factors of work experience (at least 15 years) and educational level (at least a bachelor's degree) were defined to screen the initial group. The data collection process was performed through face-to-face interviews with experts in the fire centers of two major process industries, a large urban fire department, and correspondence with faculty members of two prestigious universities. Based on the inclusion criteria, four firefighters were selected to enter the study. Then, we examined the main steps of firefighters' dispatch operation for fire response based on the defined procedure. The Hierarchical Task Analysis (HTA) technique was used to analyze the initial stages of fire response assignments. This analysis technique included all activities from receiving a fire alarm to dismounting the fire truck at the incident scene.

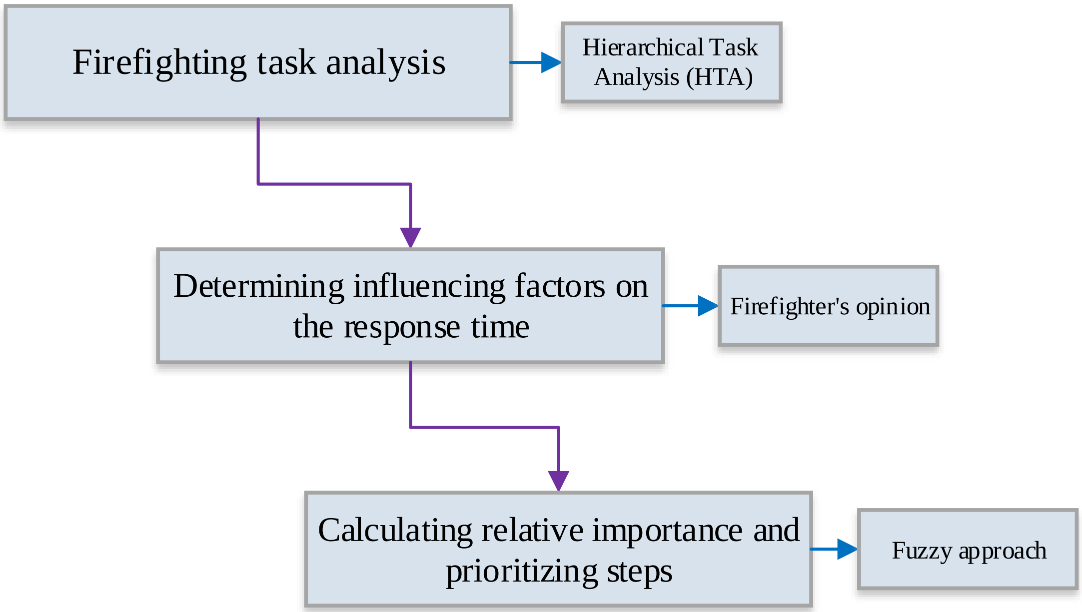

Figure 1. Time delay factors for industrial fire response steps

Determining influencing factors on the response time:

We identified the influencing factors with potential impacts on each emergency response time task in the second phase. Therefore, we developed a preliminary list of influencing factors with hindering effects on the response time through a literature review and an initial interview with an expert panel. This preliminary list included various equipment, location, and organizational factors with the potential impact on the response time. Then, the respondents were asked to determine the factors with the most negative influences on response time. Based on their responses, we corrected some items and added some factors. Finally, all probable influencing factors on the response time at the end of this step were added. As it is well known, many factors can influence response-related activities. Therefore, it was necessary to prioritize the importance of the selected influencing factors.

Calculating relative importance and prioritizing steps:

In this step, we developed a specialized weighting tool to determine the importance of each influential factor. A matrix was designed to make a pairwise comparison of the selected factors based on the verbal expression (see Table 1). To get the preferred ranking of criteria, if factor A was way much more important than factor B, the respondent was asked to assign 5. As shown in Table 1, we assigned fuzzy numbers to the variables and the weighted numbers, by which fuzzy operations were performed on weighting the influencing factors. Then, we determined the importance of all factors to each other based on the opinions of the relevant experts. Finally, the calculated fuzzy weights were entered into the Chang fuzzy system. The average fuzzy weights were calculated based on the weight of the verbal expression tables by the experts. On the other hand, mathematical relationships considering Chang's fuzzy approach were developed using Excel software.

Table 1. Change method verbal expressions weight

Verbal expressions	Weight definition	Fuzzy numbers in the Chang model
Equal importance	1	(1, 1, 1)
A little more importance	2	(1, 1.5, 2)
Relatively more importance	3	(1.5, 2, 2.5)
Much more importance	4	(2, 2.5, 3)
Very much more importance	5	(2.5, 3, 3.5)

Finally, the calculated mean was entered into Excel software. Based on the relationships, the final weight of each factor was estimated, inducing a delay in response time. After determining the indices and options studied, the relative weights of each paired matrix were calculated using the Extent Analysis (EA) method. Then, the pairwise comparison matrix of the indices was calculated by the participants based on the set coefficients. Then, the relative weights of the indices were multiplied by the relative weights of the options. Consequently, the items selected were ranked based on the above steps.

CALCULATIONS

Hierarchical task analysis (HTA):

HTA is a widely used cohesive structure to analyze specific tasks, particularly in safety and ergonomics studies since the 1980s [46-49]. In HTA, the main goal is breaking down a goal into tasks, and as the process continues, researchers can identify all tasks in the jobs. The primary purpose of this method is to fully define tasks and identify the factors that affect the overall goal. The approach is top-down, and thus all tasks were identified with one main goal [46].

Chang's fuzzy approach:

Chang's fuzzy approach is based on the Extent Analysis (EA) method. In the EA method, for each pair of comparisons matrix, the value of S_k, which is a triangular number, was calculated based on Equation 1[50].

$$sk = \sum_{j=1}^{n} Mkl \times \left[\sum_{i=1}^{m}\sum_{j=1}^{n} Mij\right]^{-1} \qquad (1)$$

In this model, after calculating the s_ks, their large degree should be calculated relative to each other. In general, if M1 and M2 are two fuzzy triangular numbers, the large degree of M1 over M2, denoted by V (M1 ≥ M2), is defined as Equation 2:

$$\begin{cases} V(\,M1\ \geq M2\,) = 1 \text{ if } m1\ \geq m2 \\ V(\,M1\ \geq M2\,) = hgt(M1\ \cap M2) \text{ otherwise} \end{cases} \quad (2)$$

Then, the weighting of the indices in the paired comparison matrix is calculated by Equation 3:

$$W'(xi) = Min\{V(Si\ \geq Sk)\}, k = 1,2, \dots, n\ , k \neq i \ (3)$$

Therefore, the weight vector of the indices will be in Equation 4:

$$W' = [W'(c1),\ W'(c2), \dots, W'(cn)]T \ (4)$$

Where, W' is the vector of fuzzy non-normal AHP coefficients.

FINDINGS/ RESULTS

According to the Hierarchical Task Analysis (HTA) result, from receiving the initial alarm to the starting response operation at the incident scene, the firefighting operation consisted of seven main steps, illustrated in Fig 2. Accordingly, these seven steps construct the other phases of the fuzzy system. Also, we identified the delay factors influencing each step. In this step, we considered the final consensus of the experts. Table 2 demonstrates these time-delay factors.

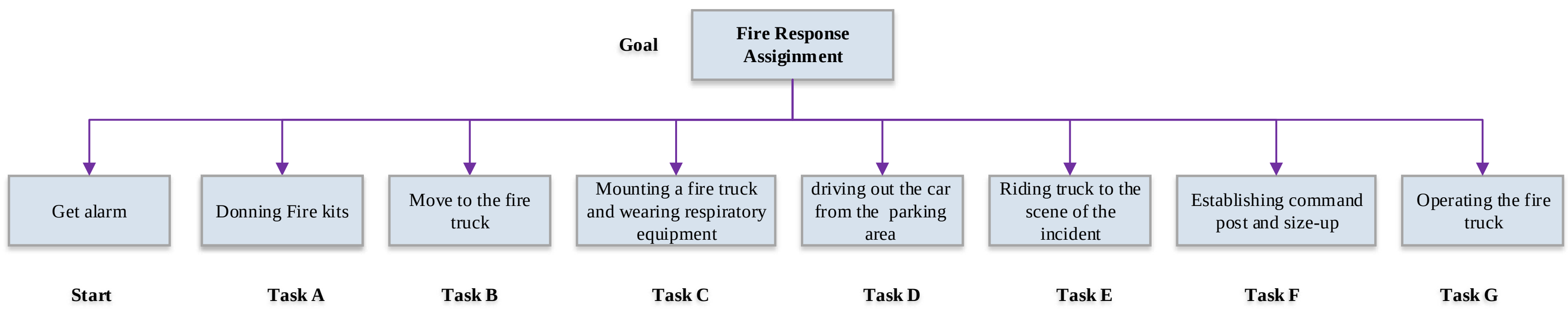

Figure 2. HTA results

Table 2. Firefighting operations' main steps

Tasks	Influencing factors	Identifier
Wearing protective equipment (firefighting garments)	Wearing clothing and boots	A1
	Incorrect size of clothing and boot	A2
	Presence of miscellaneous people in the firefighters' room	A3
	Inadequate previous drills related to wearing clothes	A4
	Small physical space for preparation	A5
	Individual factors such as stress, fatigue, and shiftwork	A6
	Keeping of clothes and PPE disordered	A7
Moving toward fire truck	Obstacles on the way (small door, uneven path, and road obstacles)	B1
	Long-distance between the firefighter's room and vehicle parking area	B2
	Inadequate lighting of the fire station at night	B3
	Inadequate parking space	B4
	Miscellaneous people on the route between the firefighter's room and the parking area	B5
Mounting a fire truck and wearing respiratory equipment	High height car chassis	C1
	Weight of the breathing apparatus	C2
	Adjust the breathing apparatus strap	C3
	Breathing apparatus belt wear-out	C4
	Insufficient interior space for breathing apparatus replacement	C5
Getting out of the parking area	Existence of barriers (like columns) in the parking space	D1
	Improperly parked truck by the previous driver	D2
	Parking space inaccessibility	D3
	Vehicle compressed air system leakage (technical vehicle defect)	D4
	Blocking the exit of the parking lot by other cars or obstacles	D5
	Insufficient driver skills	D6
Driving truck to the incident scene	Complete or partial blockage of the route (busy due to traffic jams and various car parks on the route)	E1
	Selecting improper dispatch root (choosing the wrong path and blocking path)	E2
	Inadequate communication with the fire control room	E3
Establishing command post and incident size-up	Crowded at the accident scene	F1
	Improper location for the fire truck at the scene (too close or far to the incident scene and hydrant)	F2
	Type and severity of the accident (toxicological, fire, and explosion)	F3
Operating the fire truck	No hydrants around the incident scene	G1
	Unclear duties and responsibilities for operating the fire engine	G2

	The presence of miscellaneous people at the incident scene	G3
	A technical defect in firefighting pumper and equipment	G4
	Low level of firefighters' skill in operating the engine	G5

Calculating and prioritizing results:

Table 3 shows the average of expert opinions (AEO), and Table 4 shows the normalized average of expert opinions (NAEO). Based on the evaluations, the final weights of the tasks of the alarm response were obtained as shown in Table 5 and the related results have been presented in Figure 3. Accordingly, most steps had approximately the same importance, but the importance of step F (establishing command post and size-up) was more than other stages (with an average weight of 0.145). There were identified factors that had the highest weights and most remarkable effect on the response time to fire alarms, including the improper location of the fire truck, adjusting the BA strap due to use by different people, crowded at the accident scene, type, and severity of the accident with a weight of 0.049, 0.0485, 0.0481, and 0.0479.

Figure 4 shows the sequential ranking of the influencing delay factors. However, there were factors that had the least effect on the response time, including unsuitable size for clothing and boot, BA weight, and high height of car chassis with weights of 0.0003, 0.002, and 0.0073.

Table 3. AEO on the importance of fire alarm response stages.

Criteria	A	B	C	D	E	F	G
A	(1.00,1.00,1.00)	(1.38,1.50,1.63)	(0.88,1.04,1.25)	(1.50,1.75,2.00)	(1.45,1.75,2.08)	(0.40,0.50,0.68)	(0.40,0.50,0.68)
B	(0.62,0.66,0.73)	(1.00,1.00,1.00)	(0.39,0.49,0.67)	(0.58,0.67,0.83)	(0.43,0.54,0.75)	(0.29,0.35,0.43)	(0.30,0.35,0.43)
C	(0.80,0.96,1.14)	(1.50,2.04,2.56)	(1.00,1.00,1.00)	(1.50,2.00,2.50)	(1.23,1.54,1.92)	(0.41,0.52,0.71)	(0.98,1.25,1.54)
D	(0.50,0.57,0.66)	(1.20,1.50,1.74)	(0.40,0.50,0.66)	(1.00,1.00,1.00)	(0.35,0.43,0.54)	(0.33,0.39,0.49)	(0.30,0.35,0.43)
E	(0.48,0.57,0.69)	(1.34,1.85,2.35)	(0.52,0.65,0.82)	(1.85,2.35,2.88)	(1.00,1.00,1.00)	(0.38,0.47,0.64)	(0.40,0.50,0.68)
F	(1.47,2.01,2.52)	(2.35,2.88,3.37)	(1.42,1.94,2.45)	(2.04,2.56,3.07)	(1.56,2.11,2.64)	(1.00,1.00,1.00)	(1.13,1.50,1.88)
G	(1.47,2.01,2.52)	(2.35,2.88,3.37)	(0.65,0.80,1.02)	(2.35,2.88,3.37)	(1.47,2.01,2.52)	(0.53,0.66,0.88)	(1.00,1.00,1.00)

Table 4. NAEO on the importance of responding to an alarm.

Criteria	**A**	**B**	**C**	**D**	**E**	**F**	**G**
A	(0.33,0.33,0.33)	(0.31,0.33,0.36)	(0.28,0.33,0.40)	(0.29,0.33,0.38)	(0.28,0.33,0.39)	(0.25,0.32,0.43)	(0.25,0.32,0.43)
B	(0.31,0.33,0.36)	(0.33,0.33,0.33)	(0.25,0.32,0.43)	(0.27,0.32,0.40)	(0.25,0.32,0.44)	(0.28,0.33,0.40)	(0.28,0.33,0.40)
C	(0.28,0.33,0.39)	(0.25,0.34,0.42)	(0.33,0.33,0.33)	(0.25,0.33,0.42)	(0.26,0.33,0.41)	(0.25,0.32,0.43)	(0.26,0.33,0.41)
D	(0.29,0.33,0.38)	(0.27,0.39,0.39)	(0.26,0.32,0.42)	(0.33,0.33,0.33)	(0.27,0.32,0.41)	(0.27,0.32,0.41)	(0.28,0.33,0.40)
E	(0.28,0.33,0.40)	(0.24,0.33,0.42)	(0.26,0.33,0.41)	(0.26,0.33,0.41)	(0.33,0.33,0.33)	(0.25,0.32,0.43)	(0.25,0.32,0.43)
F	(0.25,0.34,0.42)	(0.27,0.34,0.39)	(0.24,0.33,0.42)	(0.27,0.33,0.40)	(0.25,0.34,0.42)	(0.33,0.33,0.33)	(0.25,0.33,0.42)
G	(0.25,0.34,0.42)	(0.27,0.34,0.39)	(0.26,0.32,0.41)	(0.27,0.34,0.39)	(0.25,0.34,0.42)	(0.26,0.32,0.42)	(0.33,0.33,0.33)

Table 5. Final weight of the steps forming the firefighter's response to the alarms

Criteria	Abnormal weight	Normal weight
Wearing protective equipment (A)	0.982	0.143
Moving toward fire truck (B)	0.968	0.141
Mounting a fire truck and wearing respiratory equipment (C)	0.991	0.144
Getting out of the parking area (D)	0.983	0.143
Driving truck to the incident scene (E)	0.975	0.141
Establishing command post and incident size-up (F)	1	0.145
Operating the fire truck (G)	0.991	0.144
Total weights	Σwi=6.89041	Σwi=1

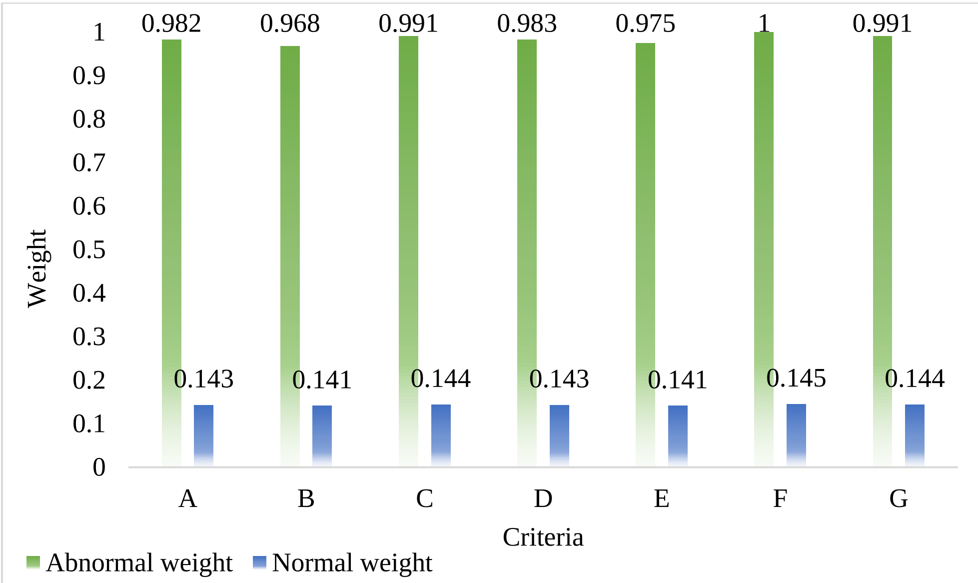

Figure 3. The final weight of the steps forming the firefighter's response to the alarms.

Table 6. Firefighter’s response time final rankings for influencing factors.

Step	Weight	Influencing factor	Local weight	General weight	Rank
Wearing protective equipment	0.143	A1	0.165	0.0236	22
		A2	0.002	0.0003	27
		A3	0.165	0.0236	22
		A4	0.168	0.024	21
		A5	0.165	0.0236	22
		A6	0.167	0.0239	21
		A7	0.168	0.024	21
Moving toward fire truck	0.141	B1	0.203	0.0286	13
		B2	0.198	0.0279	17
		B3	0.201	0.0283	16
		B4	0.202	0.0285	14
		B5	0.194	0.0274	18
Mounting the fire truck and wearing respiratory equipment	0.144	C1	0.051	0.0073	25
		C2	0.015	0.0022	26
		C3	0.337	0.0485	2

		C4	0.281	0.0405	9
		C5	0.313	0.0451	8
Getting out of the parking area	0.143	D1	0.163	0.0233	23
		D2	0.165	0.0236	22
		D3	0.162	0.0232	24
		D4	0.170	0.0243	19
		D5	0.169	0.0242	20
		D6	0.168	0.0240	21
Driving truck to the incident scene	0.141	E1	0.337	0.0475	5
		E2	0.334	0.0471	6
		E3	0.328	0.0462	7
Establishing command post and size-up	0.145	F1	0.332	0.0481	3
		F2	0.338	0.049	1
		F3	0.330	0.0479	4
Operating the fire truck	0.144	G1	0.0289	0.0289	11
		G2	0.0287	0.0287	12
		G3	0.0284	0.0284	15
		G4	0.0295	0.0295	10
		G5	0.0284	0.0284	15

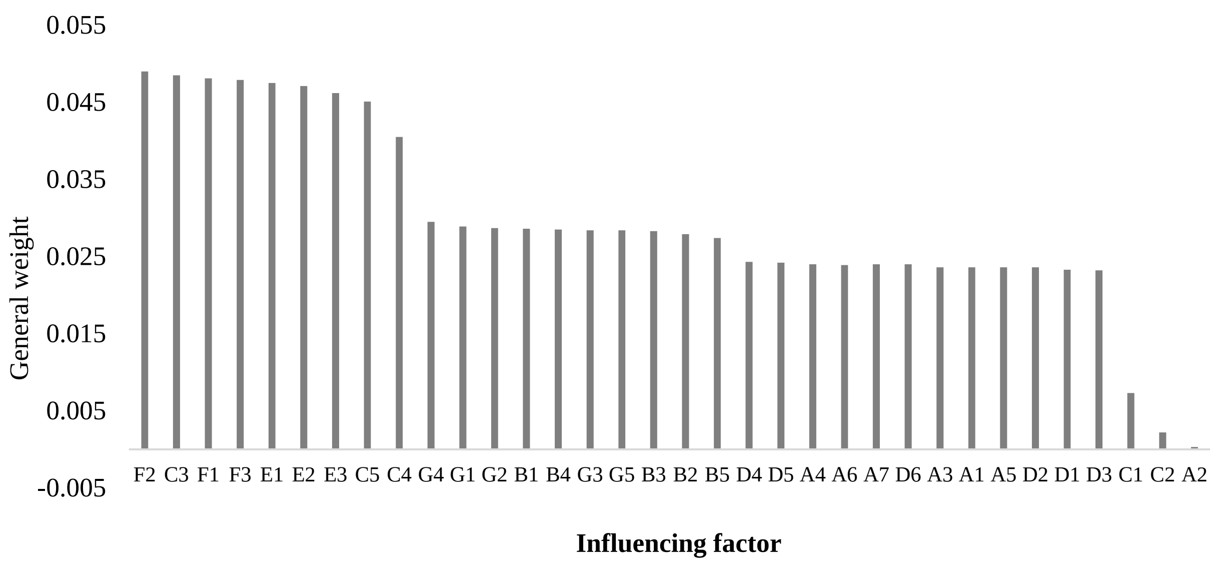

Figure 4. Firefighter's response time final rankings for influencing factors.

DISCUSSION

This study aimed to determine the delay factors affecting firefighters' response time in the industrial firefighting sector. Firstly, we performed the emergency response task analysis. Thereafter, response times for influencing factors in each step were identified. Then, a pairwise comparison was used to determine the importance of each task and its influencing factors. Finally, a fuzzy approach was used to prioritize these factors. This study showed that establishing command posts and size-up activities had a significant impact on the firefighter's response time. This step included wrong locations of fire apparatus, aggregation of the population at the incident scene, and incident complexity. Utilizing the Incident Command System (ICS) is a proven measure to manage the incident scene and establish a command post. ICS uses some definitive principles to control irregularity and coordinate shared activities. It can be concluded that ICS would improve response time.

Consequently, establishing command posts and size-up activities as the most effective phase were hindering factors for the response time. This finding was in contrast to the findings of Subramaniam et al. in Malaysia, which reported that the interval between the fire alarm and the arrival of the fire engine (dispatch phase) had the most significant impact on the response time [7]. It would be due to the differences in the current study’s scope as we investigated the industrial domain, while Subramaniam conducted his study in the municipal scope. The findings of Chang's fuzzy approach also showed that the conditions of the incident scene and route conditions to the incident scene had a substantial impact on the response time. The conditions at the incident scene were a function of the type and location of the incident. This finding was in line with that of Jaldell et al. that type of accident location had a significant effect on the response time and the rate of fire fatalities [16].

The findings showed that the most influential parameters on the response time, such as correctly locating the fire apparatus at the incident scene and adjusting the breathing apparatus (BA) were under the fire department's control. However, firefighters only had no control over the number of people on the incident scene. It is of particular importance to training firefighters and drivers to overcome these delay factors. In addition, practical exercises might improve the response time and decrease the identified delay factors. Moreover, an appropriate location for fire trucks, wearing protective equipment, and wearing BA should be taken into account more often than before. Therefore, it is recommended to consider planning and organizing the practical exercises, evaluating performance, and implementing corrective actions. In addition, to reduce the response time, it is necessary to collaborate with other departments like the security department at the incident scene to disperse the population present at the scene, isolate all routes to the incident, and control the traffic flow. To coordinate with other agencies or departments, pre-planning, joint exercises, and utilizing the Unified Command System (UCS) can minimize inconsistency at the incident scene and decrease the response time. The response team's coordination with the dispatch center or control room can also improve activities like path-finding and crossing jammed or congested routes. This finding was in line with that of Aleisa et al. The results of simulation of firefighting operations in Kuwait showed that strengthening the navigation system and central planning could reduce firefighters' response time by up to % 32 [11].

The findings also showed that the type and severity of the accident had a significant impact on the firefighters' response time. It can be concluded that the size of the incident had a direct relationship with a longer response and preparation time. Therefore, although the type and severity of an incident do not have an apparent effect on the response time, the experience of the firefighting team has shown that many invisible intermediaries such as psychological distress can create this relationship [51]. Pre-incident planning had a significant impact on reducing response time and logistic preparation. In addition, it could be found that the psychological effects of a simple incident on the response team and, subsequently, the response time might be significantly different from those of major incidents [52]. On this basis, the psychological effects of the firefighting team had an invisible relationship between the severity of the accident and the response time. Equipment maintenance and monitoring were other factors that

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highly impacted the response time. Many studies have revealed the positive effects of maintenance on safety performance [53-56]. Due to the lack of similar studies in the industrial sector, it was not possible to compare the results of this study with other studies.

The findings also showed that the anthropometric characteristics of firefighting equipment and the design characteristics of the fire station had the least impact on the response time. It should be noted that this finding could be due to the fact that all equipment and tools were fitted for the participants and had observed design requirements. Although, in the previous studies, the effect of ergonomic factors on the performance of emergency response teams was taken into account [22, 47]. In the current study, the preference of other parameters in the firefighting process was evaluated so we did not investigate this factor.

The findings of the present study would be useful in pre-incident planning activities. It is necessary to pay more attention to insignificant incidents of firefighting deployment. In addition, exercises might reduce the response time. These exercises include establishing the command post, incident size-up, wearing BA, and other PPE. Due to time and resources limit, it would be interesting to investigate the response time using techniques such as Time and Motion Analysis (TMA) or Just in Time (JIT) study for fire operations. In addition, reducing the response time is an inherent part of performance management in firefighting organizations. Thus, it is recommended to improve the response time performance, and planning, and decrease delay factors.

CONCLUSION

The results of the current study showed that hierarchical analysis in the form of a fuzzy approach (FHTA) would be useful in identifying and prioritizing the factors influencing firefighting operations as a foundation in emergency management planning. It is recommended that future studies use the approach proposed in this study to evaluate and improve the performance of other sectors involved in crisis management.

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CONFLICT OF INTERESTING

The authors have declared that no competing interests exist.

REFERENCES

1. Aliabadi MM, Gholamizadeh K. Locating urban CNG stations using quantitative risk assessment: using the Bayesian network. Safety and Reliability. 2021;40(1):48-64.
2. Industrial and Manufacturing Property Fires. Fact Sheet. Massachusetts.USA: National Fire Protection Association(NFPA); 2016.
3. Paulin Jr AW, Woods GE, editors. Economic Impact of Current SIF, Flexibility, Inspection and Manufacturing Changes As They Relate to the B31 Piping Codes. Pressure Vessels and Piping Conference; 2019: American Society of Mechanical Engineers.
4. Bansal A. Industrial Accidents and their Prevention: A Case of Satluj Jal Viduat Nigam Limited, Shimla, Himachal Pradesh. Intel Prop Intel Prop Rights. 2016;4:171.
5. Accident Statistics in Iranian Industries. Iran: Organization of Statistics and Informations; 2017.
6. Oil and Gas Industry Fatal and Nonfatal Occupational Injuries. Fact Sheet. Washington, DC_USA: Bureau of Labor Statistics (BLS); April 20, 2010.
7. Subramaniam C, Ali H, Shamsudin FM. Initial emergency response performance of fire fighters in Malaysia. International Journal of Public Sector Management. 2012.
8. Feng Y, Cui S. A review of emergency response in disasters: Present and future perspectives. Natural Hazards. 2021;105(1):1109-38.
9. Wu B, Zhang J, Yip TL, Guedes Soares C. A quantitative decision-making model for emergency response to oil spill from ships. Maritime Policy & Management. 2021;48(3):299-315.
10. Nosov P, Cherniavskyi V, Zinchenko S, Popovych I, Nahrybelnyi YA, Nosova H. Identification of marine emergency response of electronic navigation operator. 2021.
11. Aleisa E, Savsar M, editors. Response Time Analysis of Firefighting Operations Using Discrete Event Simulation. 2014 UKSim-AMSS 16th International Conference on Computer Modelling and Simulation; 2014: IEEE.
12. Snyder NA, Cinelli ME. Aperture Crossing in Virtual Reality: Physical Fatigue Delays Response Time. Journal of Motor Behavior. 2021:1-9.
13. Zarei E, Gholamizadeh K, Khan F, Khakzad N. A dynamic domino effect risk analysis model for rail transport of hazardous material. Journal of Loss Prevention in the Process Industries. 2022;74:104666.
14. Lee S, Jang JW, Kim D-Y. Emergency vehicle priority signal system based on deep learning using acoustic data. Journal of Platform Technology. 2021;9(3):44-51.
15. Mahmoudi H, Pishvaei MS, Saberian P, Slogan M. Presenting A Multi-objective Location Model in GIS Environment: A Case Study in East Tehran Emergency Stations. Health in Emergencies and Disasters. 2021;6(4):235-44.
16. Jaldell H. How important is the time factor? Saving lives using fire and rescue services. Fire technology. 2017;53(2):695-708.
17. Lu L, Peng C, Zhu J, Satoh K, Wang D, Wang Y. Correlation between fire attendance time and burned area based on fire statistical data of Japan and China. Fire Technology. 2014;50(4):851-72.
18. Buffington T, Ezekoye OA. Statistical Analysis of Fire Department Response Times and Effects on Fire Outcomes in the United States. Fire Technology. 2019;55(6):2369-93.
19. Zarei E, Khan F, Abbassi R. Importance of human reliability in process operation: a critical analysis. Reliability Engineering & System Safety. 2021;211:107607.
20. Zarei E, Ramavandi B, Darabi AH, Omidvar M. A framework for resilience assessment in process systems using a fuzzy hybrid MCDM model. Journal of Loss Prevention in the Process Industries. 2021;69:104375.
21. Wang D, Lu L, Zhu J, Yao J, Wang Y, Liao G. Study on correlation between fire fighting time and fire loss in urban building based on statistical data. Journal of Civil Engineering and Management. 2016;22(7):874-81.
22. Association NFP. NFPA 1710, standard for the organization and deployment of fire suppression operations, emergency medical operations, and special operations to the public by career fire departments: National Fire Protection Association; 2010.
23. Hansen R. Pre-incident planning of fires in underground hard rock mines: Old and new risks.

TheAustralian Journal of Emergency Management. 2021;36(4):68-74.
24. Wild J, Greenberg N, Moulds ML, Sharp M-L, Fear N, Harvey S, et al. Pre-incident training to build resilience in first responders: recommendations on what to and what not to do. Psychiatry. 2020;83(2):128-42.
25. Eskandari S, Chuvieco E. Fire danger assessment in Iran based on geospatial information. International Journal of Applied Earth Observation and Geoinformation. 2015;42:57-64.
26. Mohammadfam I, Gholamizadeh K. Investigation of causes of plasco building accident in Iran using timed MTO and ACCIMAP methods. Journal of Failure Analysis and Prevention. 2020;20(6):2087-96.
27. Williams-Bell FM, Boisseau G, McGill J, Kostiuk A, Hughson RL. Air management and physiological responses during simulated firefighting tasks in a high-rise structure. Applied ergonomics. 2010;41(2):251-9.
28. Wilde ET. Do emergency medical system response times matter for health outcomes? Health economics. 2013;22(7):790-806.
29. McCoy CE, Menchine M, Sampson S, Anderson C, Kahn C. Emergency medical services out-of-hospital scene and transport times and their association with mortality in trauma patients presenting to an urban Level I trauma center. Annals of emergency medicine. 2013;61(2):167-74.
30. Blanchard IE, Doig CJ, Hagel BE, Anton AR, Zygun DA, Kortbeek JB, et al. Emergency medical services response time and mortality in an urban setting. Prehospital Emergency Care. 2012;16(1):142-51.
31. Harmsen A, Giannakopoulos G, Moerbeek P, Jansma E, Bonjer H, Bloemers F. The influence of prehospital time on trauma patients outcome: a systematic review. Injury. 2015;46(4):602-9.
32. Picado-Aguilar G, Aguero-Valverde J. Emergency response times and crash risk: An analysis framework for Costa Rica. Journal of Transport & Health. 2020;16:100818.
33. Sund B, Svensson L, Rosenqvist M, Hollenberg J. Favourable cost-benefit in an early defibrillation programme using dual dispatch of ambulance and fire services in out-of-hospital cardiac arrest. The European Journal of Health Economics. 2012;13(6):811-8.
34. Jaldell H, Lebnak P, Amornpetchsathaporn A. Time is money, but how much? The monetary value of response time for Thai ambulance emergency services. Value in health. 2014;17(5):555-60.
35. Zhao M, Liu Z, Wang S, editors. Research on Simulation and Analysis of Fire Emergency Decision. 7th International Conference on Education, Management, Information and Mechanical Engineering (EMIM 2017); 2017: Atlantis Press.
36. Cabral ELdS, Castro WRS, Florentino DRdM, Viana DdA, Costa JFd, Souza RPd, et al. Response time in the emergency services. Systematic review1. Acta cirurgica brasileira. 2018;33:1110-21.
37. Yeboah G. FIRST RESPONDERS’EMERGENCY RESPONSE TIME ANALYSIS: CITY OF SASKATOON CASE STUDY: University of Saskatchewan Saskatoon; 2017.
38. Challands N. The relationships between fire service response time and fire outcomes. Fire technology. 2010;46(3):665-76.
39. Tzavella K, Fekete A, Fiedrich F. Opportunities provided by geographic information systems and volunteered geographic information for a timely emergency response during flood events in Cologne, Germany. Natural Hazards. 2018;91(1):29-57.
40. Gholamizadeh K, Kalatpour O, Mohammadfam I. Evaluation of health consequences in chemicals road transport accidents using a fuzzy approach. Journal of Occupational Hygiene Engineering. 2019;6(3):1-8.
41. Gholamizadeh K, Zarei E, Omidvar M, Yazdi M. Fuzzy Sets Theory and Human Reliability: Review, Applications, and Contributions. Linguistic Methods Under Fuzzy Information in System Safety and Reliability Analysis. 2022:91-137.
42. Mohammadfam I, Gholamizadeh K. Developing a Comprehensive Technique for Investigating Hazmat Transport Accidents. Journal of Failure Analysis and Prevention. 2021;21(4):1362-73.
43. Mohammadfam I, Gholamizadeh K. Assessment of Security Risks by FEMA and Fuzzy FEMA

Methods, A Case Study: Combined Cycle Power Plant. Journal of Occupational Hygiene Engineering Volume. 2021;8(2):15-23.

44. Mohammadfam I, Kalatpour O, Gholamizadeh K. Quantitative assessment of safety and health risks in HAZMAT road transport using a hybrid approach: a case study in Tehran. ACS Chemical Health & Safety. 2020;27(4):240-50.
45. Mohammadfam I, Zarei E, Yazdi M, Gholamizadeh K. Quantitative Risk Analysis on Rail Transportation of Hazardous Materials. Mathematical Problems in Engineering. 2022;2022:6162829.
46. Dancygier B. The Cambridge handbook of cognitive linguistics: Cambridge University Press; 2017.
47. Promann M, Zhang T. Applying hierarchical task analysis method to discovery layer evaluation. Information Technology and Libraries. 2015;34(1):77-105.
48. Tripathi B, Rajesh R, Maiti J. Ergonomic evaluation of billet mould maintenance using hierarchical task analysis, biomechanical modeling and digital human modeling. Computer-Aided Design and Applications. 2015;12(3):256-69.
49. Fargnoli M, Lombardi M, Puri D. Applying Hierarchical Task Analysis to Depict Human Safety Errors during Pesticide Use in Vineyard Cultivation. Agriculture. 2019;9(7):158.
50. Chang D-Y. Applications of the extent analysis method on fuzzy AHP. European journal of operational research. 1996;95(3):649-55.
51. Janka A, Adler C, Fischer L, Perakakis P, Guerra P, Duschek S. Stress in crisis managers: evidence from self-report and psychophysiological assessments. Journal of behavioral medicine. 2015;38(6):970-83.
52. Thompson DJ, Weissbecker I, Cash E, Simpson DM, Daup M, Sephton SE. Stress and cortisol in disaster evacuees: an exploratory study on associations with social protective factors. Applied psychophysiology and biofeedback. 2015;40(1):33-44.
53. Ye Z, Xu Y, Veneziano D, Shi X. Evaluation of winter maintenance chemicals and crashes with an artificial neural network. Transportation Research Record. 2014;2440(1):43-50.
54. Frangopol DM, Tsompanakis Y. Maintenance and safety of aging infrastructure: CRC press Boca Raton, FL; 2014.
55. Kim MY, Burton M, Prozzi JA, Murphy M. Maintenance and rehabilitation project selection using artificial neural networks. 2014.
56. Frangopol D. Maintenance and safety of aging infrastructure. Edited by Dan Frangopol and Yiannis Tsompanakis. CRC Press; 2014.

APPENDIX

Demographic information of the experts' panel.

N	Expert	Job position	Work Experience (years)	Degree of education
1	Faculty member 1	Professor	25	PhD
2	Faculty member ۲	Professor	20	PhD
3	Faculty member ۳	Associate Professor	15	PhD
4	Faculty member ۴	Associate Professor	16	PhD
5	Faculty member 5	Assistant Professor	18	PhD
6	Faculty member 6	Assistant Professor	15	PhD
7	Faculty member 7	Assistant Professor	18	PhD
8	Industrial firefighter 1	Industrial fire management	19	Master
9	Industrial firefighter 2	Leader of the firefighting team	20	Bachelor
10	Industrial firefighter 3	Firetruck operator	16	Bachelor
11	Industrial firefighter 4	Firetruck operator	15	Master
12	Industrial firefighter 5	Field firefighter	16	Bachelor
13	Industrial firefighter 6	Field firefighter	19	Bachelor
14	Industrial firefighter 7	Field firefighter	20	Bachelor
15	Industrial firefighter 8	Field firefighter	23	Bachelor
16	Industrial firefighter 9	Dispatcher	21	Bachelor
17	Urban firefighter 1	Urban fire management	17	Bachelor
18	Urban firefighter 2	Field firefighter	20	Master
19	Urban firefighter 3	Field firefighter	17	Bachelor
20	Urban firefighter 4	Dispatcher	19	Bachelor

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