Research Paper

Fire Emergency Response Modeling and Analysis in Hospital Emergency Departments Using a Petri Net Model

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ABSTRACT

Background: Fire safety in emergencies and health care centers is a morally and legally sensitive issue, so if patients or staff are affected by external factors such as fire, the quality of the overall system management and health care will directly be touched. Medical centers are among the places with many fire accidents each year due to the lack of standardization of buildings in terms of fire safety. This study aimed to model and analyze the fire emergency response in emergency department of hospital by hospital fire emergency response prediction network (HFERP-net) method.

Materials and Methods: This cross-sectional study was performed in the Emergency Department of a hospital affiliated with Iranian Social Security Organization in 2019. The risk assessment of the hospital was done using (FRAME) method and after that a model was developed according to the Petri net structure for fire emergency response.

Results: Task description, task scheduling, and the relationship between them were not well defined and it was time consuming. By developing the model and performing a fire drill in the unit, the tasks being identified and the time required for the proper communication between them was reduced.

Conclusion: The results showed that the fire risk level in the studied unit was unacceptable and the fire safety principles should be upgraded to an acceptable level. This method can be effective for emergency response planning and identifying high fire risks in health centers. By performing drills, potential conflicts of the tasks and resources will be identified and then the emergency response plan can be improved.

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Introduction

The issue of fire is one of the most important and pivotal issues that affect all three areas of safety, health, and environment, and fire prevention and control are crucial [1]. Fire is a major cause of life, financial, and environmental damage to buildings and people. Statistics indicate that about 75% to 80% of fires are preventable. Therefore, by employing appropriate risk assessment [1]methods, identifying existing hazards, and implementing necessary technical and managerial measures to control or minimize the likelihood of accidents and reduce their impact, the various damages caused by fire can be significantly reduced [2]. In Iran, about 1400 people are killed in fires annually, and more than 4500 people are seriously injured [3]. Hospital buildings and medical centers, such as emergency rooms are places where many fires occur in these buildings every year [4]. In addition to having a direct role in saving lives, health care centers are a powerful symbol of social progress and a necessary condition for economic development and stability, they are among the valuable assets of any country, and their destruction will have many economic and social consequences [5]. Although hospital facilities are considered low-risk buildings in the class of buildings according to their combustible contents, but the high use of flammable chemicals, little attention to safety principles in the construction and maintenance of these buildings, as well as the characteristics of residents and visitors hospital fire safety assessments need to be multiplied [6]. According to previous studies on hospital and emergency fires, the risk in these units for reasons, such as the improper design of buildings and emergency exit doors of hospitals (a large number of visits to the emergency department and hospital) [2, 3, 7-13], lack of firefighting equipment and distance of fire station [6, 8, 14-17], lack of sufficient knowledge of employees by 77.2%, in assessing fire safety in the studied hospitals, which include issues, such as announcement, firefighting, and rapid response in case of emergency [18-21]. Individuals near emergency exits are vulnerable to injury or death from heat, smoke, and toxins. Survival chances significantly increase if evacuation occurs within 5 seconds. Given the potential lack of effective emergency response plans in hospitals and emergency units, a comprehensive evacuation plan should be developed and readily accessible to all staff and individuals within the hospital [18]. The emergency response process involves analyzing and deploying fire resources and tasks to identify and prevent incidents. For instance, increasing the number of fire hydrants improves fire control effectiveness by reducing the time fire trucks spend waiting to refill. Another factor in accelerating fire suppression is the extinguishing agent (fire extinguishing foam[2]). Proper emergency response to fire requires proper planning to identify jobs, describe the duties of individuals on emergency teams, and identify resources. The advantage of this emergency response model is to reduce or eliminate this vulnerability of all participants in the emergency plan proper understanding of their duties, improving and increasing job skills and knowledge, and improving the reliability and credibility of the emergency response plan with a pre-training process. In the absence of proper planning in the fire response model, performing maneuvers and preventive measures will cause irreparable accidents for the hospital [5, 6, 19, 21-27].

1. Risk assessment is the process of identifying, analyzing, and evaluating potential hazards to determine appropriate control measures.

Materials and Methods

This research is a cross-sectional study in the Emergency Department of the Hospital, which was conducted in 2019. First, the building risk assessment was performed using the fire risk assessment method for engineering (FRAME) method (Figure 1).

FRAME is a systematic and engineering-based approach for a comprehensive assessment of fire risk in buildings and industries. This method determines the overall level of fire risk by considering the probability of fire occurrence, the flammability of materials and structure, the potential severity and consequences of a fire, and the effectiveness of existing fire protection and extinguishing systems. This assessment aims to identify strengths and weaknesses in fire safety and to provide appropriate solutions for risk reduction, the protection of life and property, and ensuring the continuity of operations against the hazard of fire. Ultimately, FRAME helps in establishing a balanced and effective fire safety strategy.

Data collection

In this study, data collection was done by attending study units and using checklists. For risk assessment through inspections (structural information of buildings, electrical systems, fire extinguishing systems and water, electricity and gas facilities, number of employees, etc.). Also interviews with relevant officials or by referring to documents (such as emergency operation plan, ICS chart) for the required information has been conducted. According to the collected information, the result of risk assessment by the FRAME method is expressed nu-

2. It is an extinguishing agent that forms a foam layer over the fuel.

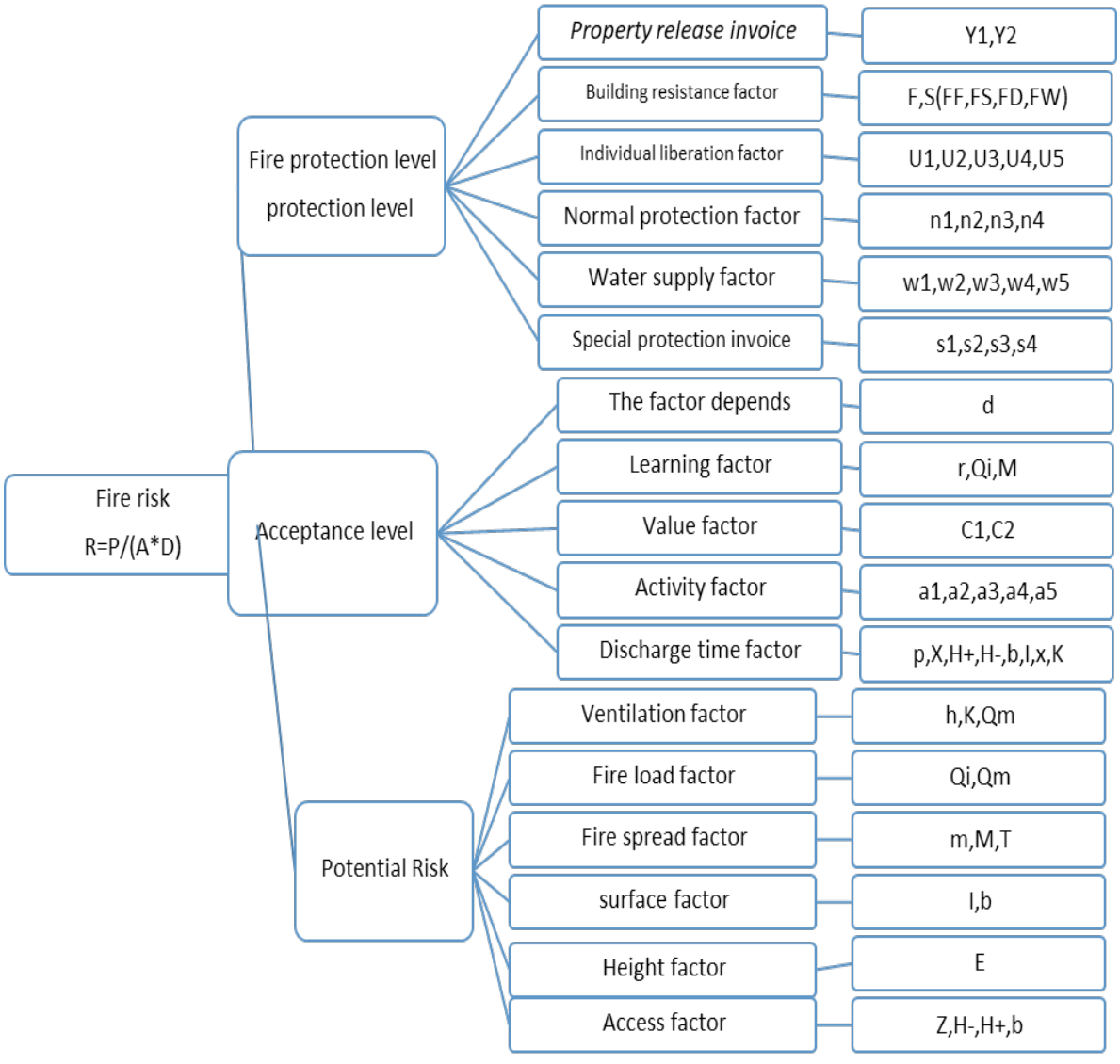

Figure 1. Graph of risk assessment steps in FRAME Method

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merically. It means that the fire risk is the quotient of the potential risk division on the level of acceptance and protection.

If the R≤1 is, the level of risk acceptance and conservation measures are equal to or higher than the potential risk, which is acceptable. The second case is R≥1, i.e. the potential risk is higher than the multiplication of risk acceptance and protective measures. As a result, protective measures are not sufficient and are unacceptable [3]. Therefore, since it is possible to cause a fire, more measures are needed, such as forming crisis teams, and in the next stage, preparing an emergency fire response process and creating an hospital fire emergency response prediction network (HFERP-net) model[3] based on the Petri network. This modeling is done in 5 steps.

Data analyses

First of all, defining tasks and a set of them and then defining the required resources and tasks. After that determining the connections and contradictions between resources and tasks and then determining the time of execution of existing tasks and resources based on the relationship of these resources with each other. Finally drawing and preparing model and chart analysis. In this model, a relationship between resources and responsibilities is prepared, which includes performing drills and

3. Deep learning model for fire risk assessment and real-time prediction

preparing the time of execution of each responsibility and using resources, so that contradictions between responsibilities and sources are revealed in these relationships to find the necessary coordination to respond to fire emergencies.

A Petri net is a set of (P, T, I, O, M), which are defined as: P: Set of places, T: Set of transfers, I: Set of inputs, O: Set of outputs, and M: Displays motion set. One of the important features of Petri Net is its applying, and in Petri networks, analysis and steps are always performed simultaneously.

Results

Risk assessment and model creation

In the evaluation, the risk numbers are shown in Table 1. Many cases have a high risk of fire, the fire risk for buildings is 1.32, for people 9.26 and for activities 4.9, all of which are higher than 1. Because the numbers are higher than an unacceptable one, it requires more control measures as well as a fire response plan. Table 1 presents risk assessment in the Emergency Department of Shahid Lavasani Hospital.

The results of the risk assessment Table in the hospital Emergency Department indicate significant differences in the level of fire risk between the three main areas of activities, personnel, and building and contents. According to the risk assessment and review of documents, it was shown that there is no specific system in the field of fire response management in the emergency. It was only a crisis chart in which the duties of people are not well defined. People at the time of crisis do not know their duty and are waiting for the orders of the upstream people, which causes a waste of time and the spread of the fire, so the response to the fire should be planned using the Petri net model.

Table 2 describes the duties and places of individuals in the event of a fire in an emergency time to extinguish the fire and save people, each person has specific tasks performed at the specified time in Table 3.

Table 3 lists the times required to perform the tasks; as shown in the table, the task is the same as the individual task. In this task, the pre-tasks time must be completed first, so that this job can complete its task properly. And if this job description requires key jobs (Resources), these key jobs must perform their tasks, and this table specifies the minimum and maximum time required for these tasks, which varies according to the circumstances. Figure 2 shows the relationship between tasks and resources. Figure 3 shows the HFERP-Net model, and Table 3 shows the timing of each task.

In Table 3, R indicates that these occupations and job descriptions are key and important in the fire response model. Their absence in the model causes a disturbance and P indicates location. In designing the scheduling model, the person who observed the fire (T1) must notify the emergency services of the occurrence of the fire (T2) and the emergency must notify the supervisor (T4), the call center (P1) and the door guard (R1). So, they prevent people from entering the scene of the fire. The call center operator (P1) notifies the fire department after receiving information from the emergency reception unit (T2) and inform to the hospital ambulance center (P2) and 125 (fire call center) (P3). At the same time, Supervisor (T4) reports the fire to the Emergency Department Manager (T7), senior public relations (T8), and crisis manager (T9). The ambulance center (P2) forwards the ambulance driver (R10) and the emergency team (R8) to the Emergency Department and 125 (fire call center) notifies the fire station (T6), so that these people can provide services, such as treating injured people and referring them to other medical centers by the emergency team (R8), ambulance driver (P10), and firefighting by the fire team (R11). The head of the Emergency Department (T7) announces the fire code to the emergency worker

Table 1. Risk assessment in the emergency department of the hospital

Variables	Activities	Persons	Building and Content
Potential risk (P)	0.42	1.26	0.63
Acceptance level (A)	0	0.19	0.79
Protection level (D)	0.39	0.72	0.61
Fire risk (R)	4.9	9.26	1.32

Table 2. List of responsibilities

Responsibility	Condition	Code
Telephone center		P1
Ambulance center	Place	P2
Fire center		P3
Emergency guard		R1
Emergency service worker		R2
Nurses		R3
Practical nurse		R4
Physician		R5
Technician		R7
Emergency team	Duties	R8
Security		R9
Ambulance driver		R10
Fire fighters		R11
Fire truck		R12
Ambulance		R13
Firefighting equipment		R14

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(R2), paramedic (R4), emergency nurses (R3), doctor (R5), and patients (T17) so that these people can perform their duties, which include extinguishing the initial fire by an emergency service worker, power outage by nurses and helping to evacuate people, evacuation of patients with beds by paramedics, examination of physical condition by doctors, and necessary instructions for the type of evacuation (with beds and equipment or without equipment). Also, the evacuation of patients should be done according to the condition (if able to walk).

The senior public relations (T8) informs the cost calculation manager (T27), the damages and Claims Manager (T26), the manager of return to normal conditions (T25), and the status assessment manager (T24). Managers have the tasks, including maintaining information about the accident situation for all hospital staff, planning and responding to emergencies in other hospitals, gathering the information needed to investigate and research the accommodation of the injured inside and outside the hospital with the cooperation of the Red Crescent and the Organization of Relief and Charities. They assess the capabilities of the hospital and report to the head of the planning unit. They start by evaluating the priority of outgoing patients, admit patients whose discharge is not possible, appoint a supervisor in the areas of incoming patients, prepare and analyze cost and damage data related to the crisis by the damage manager and receivables and maintenance of its documents. They report to the head of the Financial Administrative Unit, and prepare a report of claims and financial payment related to the head of the Financial Administration Department. The cost is calculated by the Manager every 6 hours. The crisis manager (T9) contacts the support manager (T11), the regulatory and security manager (T12), the service manager (T10), and the engineering services manager (T28) to initiate relief operations. Following this notification, the responsible units carry out operational tasks, including unloading equipment, evacuating equipment, and collecting waste after fire control under the supervision of the Director of Services and Transportation. In addition, the installation and electrical affairs unit is responsible for disconnecting and reconnecting essential utilities, including electricity, water, and gas, as required

Table 3. Specific tasks in specific time

Task	Pre-tasks	Resources	Minimum Execution Time	Maximum Execution Time
T1	Ø	R1	1	2
T2	T1	R1	1	3
T3	T2	Ø	1	3
T4	T2	Ø	1	2
T5	T3	R10, R13, R8	3	5
T6	T3	R11, R12, R14	5	8
T7	T4	R2, R3, R4, R5	2	3
T8	T4	Ø	3	5
T9	T4	Ø	3	5
T10	T9	R6	1	3
T11	T9	Ø	4	6
T12	T9	R9	2	5
T13	T4	R2	3	5
T14	T6	R3	1	2
T15	T6	R4	5	10
T16	T7	R5	8	15
T17	T7	Ø	2	4
T18	T10	R6	2	4
T19	T11	Ø	5	30
T20	T11	R7	5	10
T21	T12	R9	5	10
T22	T5	R8, R13	5	10
T23	T5	R10	5	15
T24	T8	Ø	5	10
T25	T8	R11	10	20
T26	T8	Ø	10	60
T27	T8	Ø	10	60
T28	T9	R6	10	30
T29	T13, T14, T15, T16 T17, T18, T21	Ø	5	10
T30	T25, T16, T27	Ø	5	10

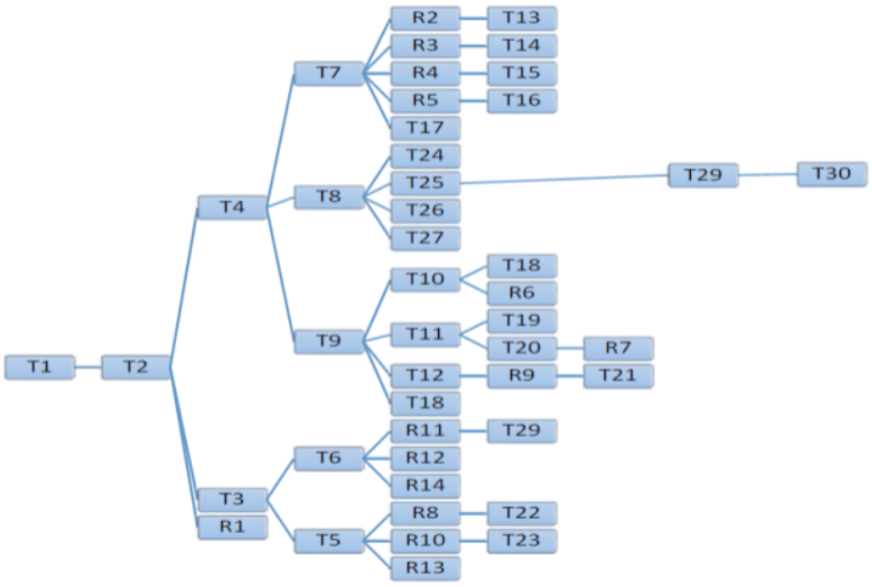

Figure 2. Relationship between tasks and resources

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during the emergency response process. The support manager and the director of law enforcement call their staff to control the transport of people and evacuate them. The Director of Engineering Services performs the task of protecting food and water reserves with the help of the chief of safety and the director of law enforcement and report to the head of the support unit and the collection of surplus and suspicious foods for transfer to places far from crisis and their sanitary disposal. The fire brigade informs the fire department manager (T29) and informs the crisis manager about the normal situation so that they can declare the normal situation (T30).

In the analysis of the data presented in Figure 4, it is observed that the most time spent is related to activities T25 to T28. These activities are usually carried out alongside other actions and mostly involve reporting, administrative coordination or documentation. However, these tasks lack a direct impact on the fire control time and are classified as non-critical tasks. In contrast, the highest critical times are related to T6 (dispatching the fire brigade) and T29 (extinguishing the fire and preventing re-ignition). T6 is mainly due to the distance of the fire from the fire station, which leads to delays in the team's arrival at the scene. This factor is one of the key points for improvement and can be cut by deploying mobile stations in high-risk areas or using early warning sys-

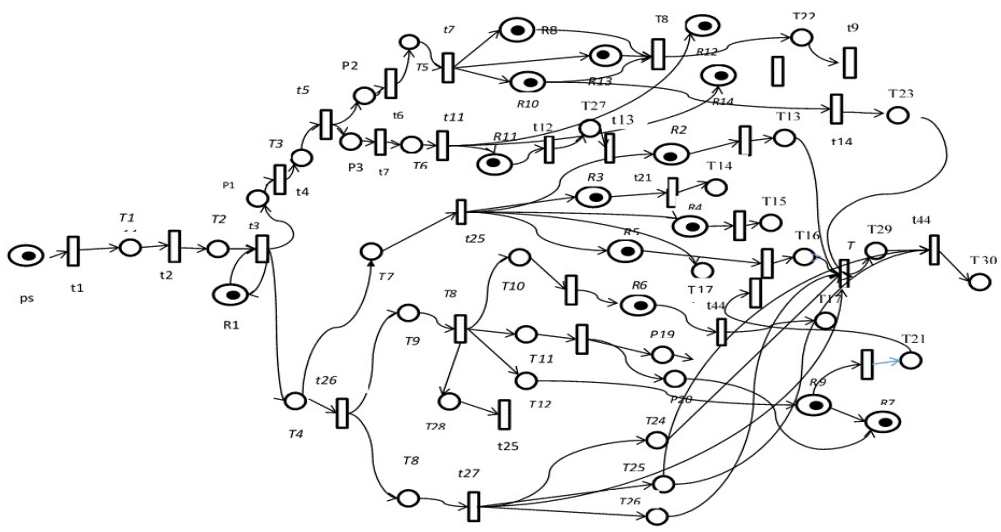

Figure 3. HFERP-net model in the emergency room of the hospital

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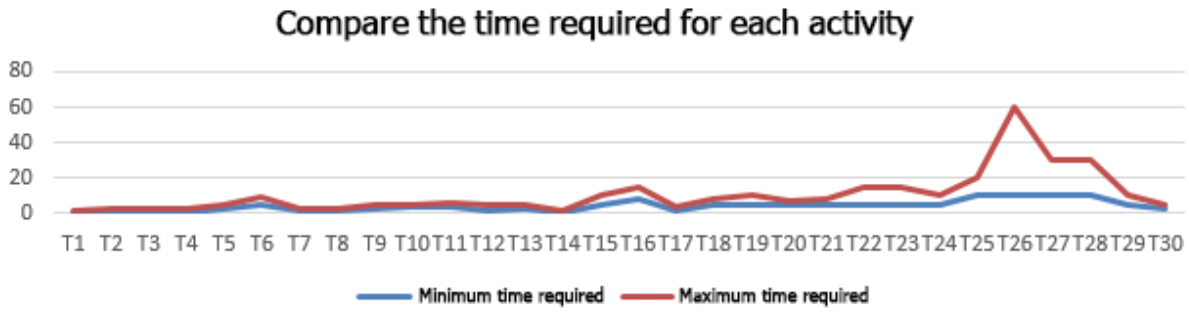

Figure 4. Comparing times required for each activity

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tems. On the other hand, T29 is related to fire suppression operations and ensuring that it is completely extinguished; the time required for which depends on factors such as fire intensity, type of fuel and equipment used. Optimizing equipment or increasing operational training can be effective in reducing this time. In addition, T16, which is related to triage (classification of casualties) by the emergency team, requires a relatively long time, as it includes providing first aid and transporting patients to medical centers. To speed up this process, medical teams based on the site or increasing medical transportation facilities can be used.

Discussion

In the hospital emergency and fire emergency response, the task description, task scheduling, and the relationship between them were not well defined and it was time consuming. By developing this model and performing a fire maneuver in a unit, it was found that due to the tasks being identified, the time required for proper communication between them decreased. All hospitals should have a strategic, comprehensive, and standard plan to deal with emergencies [28]. Weakness in management and communication, structural problems, lack of facilities, improper organization of human resources, and improper construction of hospitals are the most important problems of hospitals in the face of fire. Hospital preparedness in emergencies is related to many variables (time, geographical conditions, type of accident and the number of patients) [29]. Reconstructing a fire disaster scene, showed that it took a total of 9 minutes and 18 seconds for a patient to leave the operating room. While studying the timekeeping, they observed that this case takes only 22 seconds, so that after hearing the fire alarm, the medical staff can take the anesthetized patient out of the room but they 599 need seconds during thoracic tumor surgery for this scenario [30]. The distance of the fire station from the hospital causes the fire truck to arrive late for about 9 minutes to respond quickly to a fire in this hospital, a fire brigade in the hospital or rapid response teams must be established. In addition urban and street design is particularly effective in responding to emergency calls [19]. Those developing emergency scenarios often concentrated primarily on scenario preparation and hospital drills overlooking other crucial aspects. Consequently, given the potential weaknesses of scenarios used in the country's process industries regarding certain vital factors, training for individuals involved in scenario development based on standard principles is essential, making the proposed model necessary [22]. Utilizing a Petri net, this model systematically presents and executes actions. It assesses coordination in drills, message volume, and appropriate resource sharing timing. This net serves as a training tool to identify weaknesses, analyze key process points, and improve emergency response efficiency, ensuring all participants in the emergency program understand their roles during a fire and contribute to increased system efficiency [14]. In this model, decision-making strategies at the level of incident and response should be managed [31]. The results of this model help to evaluate and understand the effects of fire risks but some points need to be improved, resulting in increasing the level of safety, reducing hospital costs by increasing the rapid response to prevent equipment damage and injury to people, and increasing the hospital's credibility [25, 32]. Also predicting evacuation duration can provide accurate information and true analyses of these events for the managers. Therefore, health policy makers can promote preparedness and responsiveness during fire with appropriate plans [10, 33-34]. Jahangiri et al. proposed detailed processes and frameworks for applying Foresight to improve the future identification of disaster management [35].

Conclusion

Finally, the results showed that the fire risk level in the studied unit was unacceptable and it is necessary to improve fire safety measures to an acceptable level. The method presented in this study can be effectively used for emergency response planning and identification of high-risk areas. To improve the practical implementation of this method, it is suggested to use real-time monitoring systems for dynamic fire risk assessment. Also, conducting regular operational exercises can help identify conflicts in the allocation of tasks and resources and lead to improved emergency response plans. In line with the development of this research, future studies can investigate the feasibility of extending this method to more complex environments such as multi-unit industrial facilities or mixed environments (such as urban-industrial areas).

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Research Ethics Committee of Shahid Beheshti University of Medical Sciences, Tehran, Iran (Code: IR.SBMU.PHNS.REC.1397.069).

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Authors' contributions

Study design: Ghazaleh Monazami Tehrani; Data collection: Abbas Azizi; Data analysis: Ghazaleh Monazami Tehrani, Ali Salehi Sahlabadi, and Vafa Feyzi; Final approval: All authors.

Conflict of interest

The authors declared no conflict of interest.

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