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Research Article

Prioritization of Interventions and Technologies to Prevent Fire Spread in Hospitals

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Abstract

Background: Fire is one of the potential dangers that threatens human activities more and more. Given that, this study sought to introduce the factors preventing the spread of fire in hospitals to policymakers through prioritization based on the techniques of applied mathematics (multi-attribute decision-making technique).

Methods: This study consisted of two stages. In the first stage, through a comprehensive review of studies, factors preventing the spread of fire were identified, and then in the second stage, based on the experts' opinions, the attributes affecting the prioritization and their weights were determined. Finally, based on the Simple Additive Weighting (SAW) model, the final prioritization was done for five types of hospital buildings.

Results: Based on the literature review and experts' opinions, seven factors and four attributes were identified. The most important factors were "the use of safety architecture and equipping with appropriate emergency exit accesses according to the standard" in high-rise hospitals, "continuous firefighting training of the personnel" in wide hospitals, "use of fire extinguishing systems (automatic and manual)" in subsurface hospitals, "use of fire extinguishing systems (automatic and manual)" in combined hospitals, and "continuous firefighting training of the personnel" in portable hospitals.

Conclusions: Fire safety is not limited to the installation of a manual fire extinguisher, but for fire safety, especially in hospitals, all aspects should be considered, including the architectural form of the building, how the materials and equipment in the building caught fire, fire behavior in terms of heat transfer, the firefighting training of the personnel, recognition, and application of modern and ready-made equipment for smoke ventilation systems and fire products, automatic and manual fire alarm systems, and extinguishing systems to prevent the spread of fire.

Keywords: Hospital, Inhibitors, Fire, Safety

1. Background

Fire is a potential danger that always threatens humans and their activities, whose severity and destructive effects have increased today. Fire as an important destructive factor causes lots of human and financial losses (1). Almost every human action is accompanied by a certain degree of risk, while some actions are riskier. Risks cannot be eliminated completely but can be lowered to a tolerable or acceptable level. Thus, it is necessary to provide a consistent framework for identification, evaluation, elimination, control, prevention, attenuation, and announcement of the risks (2).

Fire is one of the most dangerous phenomena causing major casualties and financial losses in hospitals and healthcare settings. In order to prevent and control the fire sources, a risk assessment should be first conducted (3). The fire risk assessment has always been a challenging task. Performance-based approaches to fire engineering have shown that risk-based decisions and fire scenarios are fundamental elements that must be considered in fire safety strategies. A correct assessment of the fire risk allows all involved stakeholders to identify a specific strategy among a variety of possibilities. A risk assessment is the best tool to identify comparable fire protection strategies and to measure the reduction in fire risk

that can be obtained by specific prevention and protection measures, i.e., different fire safety strategies. This method allows the risk to the occupants to be evaluated separately from the risk to the building (4).

In today's world, preparedness and security in the face of adversity are essential. This issue is so important that developed countries devote an important part of their comprehensive and national planning to it (5). Fire is one of the most important dangers that threatens the buildings of industrial, commercial, educational, and medical centers of different communities. It is very difficult to evacuate due to the increase in the density of residents in these environments and the lack of quick access to outdoor space in the event of a fire. This increases the number of fire casualties (6).

Every year, a large number of hospital buildings and medical service centers catch fire. Today, fire safety is one of the most important challenges facing health managers. Thus, it seems that these buildings and the rules related to their construction do not provide sufficient safety for hospital staff, patients, and their companions (7). The results of studies show that about half of the casualties caused by fires are attributed to fires that occur in buildings. Besides, studies show that the number of fire deaths per year due to construction fires is 4 in Australia, 15 in the United Kingdom, 20 in the United States, 6.11 in Southwest Asia, 4.6 in the Eastern Mediterranean, and 6.11 in Africa. These numbers occurred per 1 million people of mentioned countries annually (6, 7).

Because fire is one of the most dangerous phenomena that cause major human and financial losses, it can be a real danger to service centers such as hospitals. Due to the fact that the residents of the hospital are generally disabled people who cannot save themselves, the fire in the hospital can cause more casualties than in any other public place. In addition, due to the presence of hospital staff as valuable human resources, as well as numerous and expensive medical devices and equipment, fires can cause irreparable damage, besides the damage to the public image of the hospital (8).

The destruction of a hospital or its damage due to fire may result in the loss of trust by local authorities, as well as injuring patients and staff to not provide health care services properly (9). In other words, if patients or staff are harmed by factors such as fire, this will have a direct impact on the quality of overall system management and health care. As a result, hospital safety against fire is one of the important factors in its maintenance and safety and should be studied and considered by managers (7, 8).

The results of a fire risk assessment to hospitals and healthcare facilities for about 300 compartments (overall size of about 60,000 m2) were analyzed, including two hospitals of about 200,000 m2 each. About 44% of the hospital facilities were at medium risk and 39% at high risk (according to Italian fire law). But, more than 60% of the hospital wards were at high risk (4), unfortunately, per 5 deaths which were related to fires occurred in India. Fire can occur to anyone, at any time, and at anywhere, including healthcare facilities. Hospital fires can be devastating in terms of loss of life, injuries to patients / staff, and loss of property / equipment, because hospitals house a large number of vulnerable people. For example, one can point to fires at AIIMS-New Delhi and SAL-Ahmedabad hospitals (10).

Studies have been taken in developed countries about fire prevention management and planning. However, in Iran, this issue has not been sufficiently addressed. According to information published by the National Fire Protection Organization, on average, more than 8,000 hospital fires occur annually worldwide. Studies have shown that if safety principles were applied in this type of fire, at least 75% of the damage could have been predicted and prevented (11).

Concerning the identification of fire hazards in various parts of hospitals, the Emergency Care Research Institute listed the top 10 technological hazards in 2009, with surgical fires ranking third. Researchers estimate that fires occur about 550 to 650 times in surgery wars in US annually. Surgical fires involve electrical equipment 68% of the time (12).

Although in developed countries, basic studies and measures have been taken for fire prevention management and planning (13), this issue remains to be addressed in Iran. From a technical point of view, for fire protection and safety, measures must be taken at three levels. The first level of protection relates to measures that prevent the onset of fire. The second level of protection is related to measures that prevent the fire from coming into contact with people in various ways and provide ways to save people. The third level of protection relates to actions that can be taken in the event of a fire, based on ensuring that people are rescued completely and correctly. A design for a building must provide complete protection by providing conditions and facilities at all three levels along with design evaluation, as well as impact assessment of those measures (7).

One of the first measures in this field can be to identify and prioritize the factors affecting the creation and spread of hospital fires, for which important methods should be used that are appropriate to the local culture of the people (13). According to experts, some managerial and planning decisions regarding disaster control, such as fire, have been made without sufficient relevant information, and the reason is the lack of appropriate protocols in this area (14). Therefore, in this regard, it is necessary to study fire safety management in hospitals. Hospital fire management and preparation of fire safety strategies begin before the construction of the hospital building. It involves the hospital designer and different levels of management in the hospital, as well as all staff, patients, companions, visitors, supplies, and equipment that includes prevention, detection, escape, rescue, miniaturiza-

tion, and firefighting. In this regard, the duties of the hospital manager and the safety manager of the hospital are the most important, as well as their roles. One of these tasks is to design a fire safety program in the hospital. Efforts should be made in the hospital safety plan to reduce the risk of death and injury to residents as much as possible and to minimize damage to the building skeleton and its contents. Fire safety methods are used to achieve these goals (8).

Existing UK government guidelines set out safety measures for hospital fires. These guidelines are new advice for the staff who should be trained in the safe selection and use of fire extinguishers, and these mentioned training must be performed by multidisciplinary team from various personnel annually. The general principles of these guidelines are to be implemented in each department using non-invasive respiratory support, especially high-flow nasal oxygen. While these guidelines are recommended every two years in the existing guidelines of the Ministry of Health, it is something rarely done in practice (15).

Since in hospital fires, the number of patients admitted to the ward is more than the number of medical staff, and they generally cannot leave the fire in time due to the type of disease or lack of familiarity with the emergency exit access, so designing necessary preparations for fire in hospital can help crisis committees to determine the type of evacuation behavior (16). The existence of the sprinkler system reduces the fire risk by an average of 48.5%. Thus, the effect of the sprinkler system on reducing the risk of fire is significant (9). The need to evacuate an ICU or operating theatre complex during a fire or other emergency is a rare event but one potentially fraught with difficulty. Not only is there a risk that patients may come to harm but also staff may be injured and unable to work. Designing newly-built or refurbished ICUs and operating theatre suites is an opportunity to incorporate mandatory fire safety features and improve the management and outcomes of such emergencies (15). The ICUs and operating theatre suites should have a bespoke emergency evacuation plan and a readily available route map. Staff should receive practical fire and evacuation training in their clinical area of work on induction and annually as part of mandatory training, including "walk-through practice" or simulation training and location of manual fire call points. The staff in charge of each shift should be able to select and operate fire extinguishers and lead an evacuation (15).

The England Association of Anesthetists and ICS have set up an expert working party as a joint venture, and some guidelines have been produced as a result of the work of this group. During the COVID-19 pandemic, issues around fire safety, emergency evacuations, and the safe use of oxygen have become especially relevant (15).

2. Objectives

Regarding the above-mentioned facts about the fire in healthcare settings, the present study sought to introduce the factors preventing the spread of fire in hospitals to policymakers through policy-making prioritization based on applied mathematics modeling

3. Methods

3.1. Identifying Factors That Prevent the Spread of Fire

To allocate resources and classify the factors preventing the spread of fire in hospitals, a comprehensive review of studies was done by searching the available databases. Three databases, including Cochrane Library, PubMed, and Scopus, were systematically searched from 2000 to March 2021. Articles that had quantitative or qualitative criteria and specific factors to prevent the spread of fire in hospitals were included in the study. The initial screening was performed by reviewing the articles' titles and abstracts. Keywords used in each database included "health center *", "hospital *", "fire prevention", and "fire".

Then, all related articles were collected and entered into EndNote version 8 software, and duplicates were removed. Finally, 20 articles entered the final phase of the study. The obtained data were synthesized thematically. The data were presented to health and fire experts in an expert panel. As a result, seven effective models were selected for five groups of hospitals (high-rise, wide, subsurface, combined, and portable), including: (1) using automatic and manual intelligent fire alarm systems, (2) using automatic and manual fire extinguishing systems, (3) using automatic carbon monoxide smoke and gas ventilation systems, (4) arranging and replacing different parts of the hospital for preventing the transmission of fire from one department to another, (5) using safety architecture and equipping with the hospital with appropriate emergency exit accesses according to standards, (6) continuous firefighting training of the personnel, and (7) using appropriate emergency exit signs and indicators.

3.2. Prioritization Through Multi-criteria Decision Making

It should be noted that in multi-criteria decision-making methods, there is no specific relationship or formula for determining the sample size, but an attempt was made to count the number of experts (5). After determining the factors to prevent the spread of fire in hospitals, for the optimal use of research, a panel of hospital and fire specialists, as well as university faculty members, was formed, "resulting in four attributes: (A) The principle of human and financial resources, (B) the principle of sup-

port facilities, (C) the principle of support related to firefighting organizations, and (D) the principle of executive coordination, which can be effective in using seven effective factors in preventing the spread of fire. In this study, to predict the factors preventing the spread of fire in hospitals, the architectures of hospitals were considered in five categories. The collected data were extracted and expressed using a simple additive weighing model (SAW) whose accuracy was confirmed. Regarding the method of selecting the experts and the selected model, according to the qualitative data of this study, using the carcass rules (17), the number of primary specialists increased to 5, and the number of specialists using the snowball method increased to 16 (18). Then, 12 factors preventing the spread of fire were discussed with them. By prioritizing these factors and with a cutting point of 75% (17), the top seven factors were selected from among the 12 factors. Finally, the seven selected models and four attributes of organizational relationship problems in hospitals were integrated for five groups of hospitals (in terms of fire exposure) with the opinion of the experts. Finally, by the multi-criteria decision-making method, fire prevention factors were prioritized for each hospital group (18).

4. Results

4.1. Identifying the Factors Preventing the Spread of fire in Hospitals

After receiving the individual opinions of experts on the importance of four attributes of organizational relationship problems in using each of the seven models, by assigning a score on the Likert scale, the average score of all comments was calculated, which is shown in Table 1 for high-rise hospitals.

Table 1. Average of Four Effective Indicators of Organizational Communication of Hospitals in Using Each of the Seven Models for High-rise Hospitals

Factors	Attributes			
	Human and Financial Resources	Support Facilities	Support Related to the Fire Department	Level of Executive Coordination
Use of intelligent fire alarm systems (automatic and manual)	3.8750	3.4375	3	3.125
Use of fire extinguishing systems (automatic and manual)	3.812	3.687	3.0625	3
Use of carbon monoxide smoke and gas ventilation systems (automatic and manual)	3.562	3.312	2.875	3
Arrangement and replacement of different wards of the hospital in order to prevent the spread of possible fires in each ward	3	3.250	3.125	2.875
Utilizing safety architecture and equipping with appropriate emergency exit accesses according to the standard	3.675	3.562	3.562	3.0625
Continuous firefighting training of the personnel	3.750	3.4375	3.375	2.9375
Using appropriate warning signs and emergency exit indicators	3.5625	3.500	2.8750	2.7500

4.2. Determining the Weights of Attributes

According to experts, the highest weight was assigned to the attribute of "human and financial resources" with a score of 0.33, and the lowest weight was assigned to the attribute of "level of executive coordination" with a score of 0.18 (Table 2).

Table 2. Final Weight of Attributes

Attributes	Weights
Human and financial resources	0.33
Support facilities	0.26
Support related to the fire department	0.23
Level of executive coordination	0.18

4.3. Prioritization of Fire Prevention Factors in High-rise Hospitals

The results in high-rise hospitals showed that the factors, using safety architecture and equipping with proper access to emergency exit as per the standard, use of fire extinguishing systems (automatic and manual), continuous firefighting training of the personnel, use of intelligent fire alarm systems (automatic and manual), use of carbon monoxide gas ventilation systems (automatic and manual), use of appropriate warning signs and emergency exit indicators, and adjustment and replacement of different parts of the hospital to prevent the spread of fire in each ward, were in order of priority to prevent the spread of fire in high-rise hospitals (Table 3).

Table 3. Results of Ranking of High-rise Hospitals After Weighting and Extraction

Factors	Total Score	Ranking
Utilizing safety architecture and equipping with appropriate emergency exit accesses according to the standard	0.971619	1
Use of fire extinguishing systems (automatic and manual)	0.955197	2
Continuous firefighting training of the personnel	0.948822	3
Use of intelligent fire alarm systems (automatic and manual)	0.946057	4
Use of carbon monoxide smoke and gas ventilation systems (automatic and manual)	0.89536	5
Use of appropriate warning signs and emergency exit indicators	0.894181	6
Arrangement and replacement of different wards of the hospital in order to prevent the spread of possible fires in each ward	0.851991	7

4.4. Prioritization of Fire Prevention Factors in Wide Hospitals

The results in large hospitals indicated that the factors, the continuous firefighting training of the personnel, the use of safety architecture and equipping with appropriate emergency exit accesses according to the standard, the use of intelligent fire alarm systems (automatic and manual), the use of fire extinguishing systems (automatic and manual), the use of appropriate emergency exit signs and indicators, the arrangement and replacement of different parts of the hospital for preventing the spread of possible fires, and the use of carbon monoxide smoke and gas ventilation systems (automatic and manual) in each ward, were in order of priority to prevent the spread of fire in wide hospitals (Table 4).

Table 4. Results of Ranking of Wide Hospitals After Weighting and Extraction

Factors	Total Score	Ranking
Continuous firefighting training of the personnel	1	1
Utilizing safety architecture and equipping with appropriate emergency exit accesses according to the standard	0.94	2
Use of intelligent fire alarm systems (automatic and manual)	0.91	3
Use of fire extinguishing systems (automatic and manual)	0.9	4
Use appropriate warning signs and emergency exit indicators	0.87	5
Arrangement and replacement of different wards of the hospital in order to prevent the spread of possible fires in each ward	0.86	6
Use of carbon monoxide smoke and gas ventilation systems (automatic and manual)	0.7	7

4.5. Prioritization of Fire Prevention Factors in Subsurface Hospitals

The results in subsurface hospitals indicated that the factors, using fire extinguishing systems (automatic and manual), using carbon monoxide smoke and gas ventilation systems (automatic and manual), using safety architecture, and equipping with appropriate emergency exit accesses according to the standard, continuous firefighting training of the personnel, the use of intelligent fire alarm systems (automatic and manual), the use of warning signs and appropriate emergency exit indicators, and the arrangement and replacement of different parts of the hospital to prevent the spread of possible fires in each ward, were in order of priority to prevent the spread of fire in subsurface

hospitals (Table 5).

Table 5. Results of Ranking of Subsurface Hospitals After Weighting and Extraction

Factors	Total Score	Ranking
Use of fire extinguishing systems (automatic and manual)	0.974328913	1
Use of carbon monoxide smoke and gas ventilation systems (automatic and manual)	0.95897748	2
Utilizing safety architecture and equipping with appropriate emergency exit accesses according to the standard	0.950311498	3
Continuous firefighting training of the personnel	0.945371351	4
Use of intelligent fire alarm systems (automatic and manual)	0.931044017	5
Use of appropriate warning signs and emergency exit indicators	0.917493645	6
Arrangement and replacement of different wards of the hospital in order to prevent the spread of possible fires in each ward	0.902106441	7

4.6. Prioritization of Fire Prevention Factors in Combined Hospitals

The results in combined hospitals indicated that the factors, using fire extinguishing systems (automatic and manual), using intelligent fire alarm systems (automatic and manual), continuous firefighting training of the personnel, using safety architecture, and equipping with appropriate emergency exit accesses according to standard, using carbon monoxide smoke and gas ventilation systems (automatically and manually), using appropriate warning signs and emergency exit indicators, and the arrangement and replacement of different parts of the hospital to prevent the spread of possible fires in each ward, were in order of priority to prevent the spread of fire in combined hospitals (Table 6).

Table 6. Results of Ranking of Combined Hospitals After Weighting and Extraction

Factors	Total Score	Ranking
Use of fire extinguishing systems (automatic and manual)	0.980877368	1
Use of intelligent fire alarm systems (automatic and manual)	0.970953515	2
Continuous firefighting training of the personnel	0.953715242	3
Utilizing safety architecture and equipping with appropriate emergency exit accesses according to the standard	0.907641193	4
Use of carbon monoxide smoke and gas ventilation systems (automatic and manual)	0.885279068	5
Use of appropriate warning signs and emergency exit indicators	0.84417479	6
Arrangement and replacement of different wards of the hospital in order to prevent the spread of possible fires in each ward	0.79904612	7

4.7. Prioritization of Fire Prevention Factors in Portable Hospitals

The results in portable hospitals indicated that the factors, the continuous firefighting training of the personnel, the use of appropriate warning signs and emergency exit indicators, the arrangement and replacement of different parts of the hospital to prevent possible fires in each ward, the use of fire extinguishing systems (automatic and manual), the use of intelligent fire alarm systems (automatic and manual), the use of safety architecture and equipping with appropriate emergency exit accesses according to the standard, and the use of carbon monoxide smoke and gas ventilation systems (automatic and manual), were in order of priority to prevent the spread of fire in portable hospitals (Table 7).

Table 7. Results of Ranking of Portable Hospitals After Weighting and Extraction

Factors	Total Score	Ranking
Continuous firefighting training of the personnel	1	1
Use of appropriate warning signs and emergency exit indicators	0.733568657	2
Arrangement and replacement of different wards of the hospital in order to prevent the spread of possible fires in each ward	0.636703674	3
Use of fire extinguishing systems (automatic and manual)	0.62826077	4
Use of intelligent fire alarm systems (automatic and manual)	0.548225055	5

5. Discussion

Protecting hospitals from fire is very important due to the presence of people with disabilities, lack of awareness, and expensive equipment and supplies. A study was conducted to simulate a fire in an ultra-high-end hospital. This descriptive cross-sectional study was performed in an ultra-high hospital (17 floors) in 2018 - 2019. By modifying the stairs and the elevator shaft, the spread of fire could be controlled effectively. To improve the level of fire risk and take appropriate measures in the event of an emergency in an ultra-high hospital, special measures, especially in the field of containment and extinguishing, included the design of the building for smoke control and the use of fire alarm systems and extinguishing systems (17).

In developing countries, no specific or a few guidelines have been published on how to evacuate patients in emergencies such as fires (19). For improving the level of fire risk in hospitals, it is necessary to take the necessary safety measures, such as designing the building for better access to exit routes and enhancing the quantity and standards of emergency exits (11).

Hospitals are divided from different perspectives, but not in terms of fire. The occurrence of unwanted fires and their spread, which depends on fire behavior and heat transfer. Also, the categorization of hospitals will be important to be based on the height, width, and depth of the building, or a combination of them, which indicate the ease or difficulty of extinguishing and rescuing people by internal factors of the hospital or external factors such as firefighters (16). This category has been approved by experts in the field of fire and hospitals and includes high-end hospitals, general hospitals, subsurface hospitals, combined hospitals, and portable hospitals. Following this classification, there are seven predetermined factors which were assessed for each category given to the four attributes. So far, there have been studies on fire safety in hospitals, which helped the researcher of this article. But in this study, an attempt was made to use all the factors affecting fire safety together to achieve the results.

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