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Development of Fire Risk Assessment Model for Hospital Buildings in Urban Areas

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ABSTRACT

Global healthcare fires cause major casualties. Despite fewer incidents in Thailand, fire prevention is crucial. This study develops a prototype of fire risk assessment model for hospital buildings in urban areas aligned with NFPA 551 and OHSAS 18001, The model comprised four steps: 1) Hazard identification and fire opportunity assessments (Sources of fire, people at risk, fire and life safety and fire protection management); 2) Fire severity assessment; 3) Fire risk level assessment and 4) Fire risk management of hospital buildings in urban areas. Data was collected through interviews with eight specialists and by testing the model with simulated scenarios by eighteen specialists. Results indicated that fire opportunities in Category 4 had the highest risk score at 64.14%, followed by Category 1 at 62.58%, Category 3 at 58%, and Category 2 at 52.53%. Calculating opportunities using an equation yielded a value of 59.85, categorizing it as "Moderate". Fire severity was assessed as "High", implying a severe impact on building occupants, potentially leading to disability or death, and significant structural damaged. A "High" fire risk level mandates proactive safety management to mitigate risks before operations commence.

1. INTRODUCTION

Hospital buildings in urban areas are usually located in highly populated community areas. As a result, a large number of people frequently visit for medical treatment. But urban space is limited, so the building construction is designed as high-rise building and large enough to serve the high demand. In addition, activities in the hospital are quite complex, for example, patients with difficulty moving or a young child. These patients have a higher potential to be exposed to pathogen, medical radiation etc. If a fire breaks out in a hospital, it will lead to a huge loss to individuals, communities, properties and facilities. So, this situation should not be allowed to occur. According to data on fire incidents in India from 2010 to 2023, most fires were caused by electrical short circuits and failures in fire protection and control systems in hospital buildings. These incidents resulted in fatalities [1], as shown in Table 1. Additionally, factors contributing to the fire included the absence of mechanized fire-fighting systems, non-compliance with fire safety laws, inadequate fire safety planning, poor maintenance of fire equipment, insufficiently trained hospital staff, the use and storage of combustible materials, ineffective emergency response procedures, legal and administrative obstacles to safety improvements, and a lack of equipment to assist patients during evacuation [2].

Thailand has compiled statistics on fire incidents in hospitals from 2016 to 2023 and found that there were 35 cases [3], as shown in Table 2.

Recognizing the importance of fire prevention and control in hospitals, the Ministry of Public Health has established the Patient and Public Health Personnel Safety Policy in 2016 and instructed all hospitals to comply with the Occupational Safety, Health and Environment Act (A.D. 2011) and related laws of fires in buildings in Thailand are Building Control Act Ministerial Regulations [4], Standards of Fire Prevention and Suppression for Management and Operation of Occupational Health and Safety in Environment Workplace [5] and other related ministerial regulations reveals that found that there are regulations regarding to fire prevention and suppression system management such as fire escape stairs, fire exits, emergency exits, safety and emergency signs, emergency power systems, elevator systems, fire alarm systems, fire extinguishing installation systems, fire pump and automatic sprinklers, lightning protection systems, floor diagrams, smoke ventilation and spread control systems, etc. However, these laws do not explicitly cover fire risk assessments. Consequently, compliance with these regulations only ensures adherence to building standards but does not necessarily guarantee an understanding of potential fire risks and their severity. A study of Fire Protection and Suppression Systems in Religious Places was conducted at Bang Phil Yai Temple in Samut Prakan. The study employed forms and risk assessment based on Ministry Regulation No. 47 (A.D. 1997), issued under the Building Control Act (A.D. 1979), and the Ministry of Industry's risk assessment criteria. While these guidelines address fire prevention and suppression system management, they lack specific guidance on problem causes and corrective actions aligned with NFPA standards [6]. The inspection of all nine buildings types under the Building Control Act (A.D. 1979) focus on the visual assessments using basic equipment

like tape measure, lux meters, sound level meters, and anemometers, etc. [7]. When a fire safety inspection forms and criteria are developed by references to the Building Control Act (A.D. 1979) and fire protection standards such as Engineering Institute of Thailand., building inspectors, building owners, and stakeholders, fire hazards can be more effectively identified. The assessment results can be used in risk assessment and fire risk analysis to evaluate actual building fire performance.

When applying NFPA 501 Guide for the Evaluation of Fire Risk Assessments, to assess the fire risk of urban hospitals in Thailand, it was found that NFPA 501 only outlines the necessary steps to cover the specified topics, not detail the procedures. This makes implementation quite challenging. While ISO 31000 Risk Management can be applied to fire risk assessment, it may not comprehensively address all potential fire hazards. Similarly, ISO 45001 Occupational Health and Safety Management System, focuses on occupational health and safety aspects and may not fully cover fire-specific threats.

The researcher team acknowledges the importance of this issue and initiates the research project "Development of Fire Risk Assessment Model for Hospital Buildings in Urban Areas" that uses the guidelines of evaluation fire risk assessment from NFPA 551 Guide for the Evaluation of Fire Risk Assessments and occupational health and safety risk assessment from OHSAS 18001: 2007 Occupational Health and Safety Management System to develop a fire risk assessment model for hospital buildings in urban areas and related documents to appropriately cover as many fire risk factors as possible.

Table 1. Prominent hospital fires in India

Year	Accident Trigger	Negligence Identified	No. of Deaths
2023	Short circuit	Fire safety system not installed; No certificate of fire equipment.	6
2022	Short circuit	Fire door width inappropriate; Exit blocked; Firefighting system not operational.	9
2021	Short circuit in radiant warmer's control panel in sick newborn care unit / in AC unit in ICU ward / in ventilator machine in ICU	Fire NOC not obtained; No firefighting system in SNCU; Fire hydrant line redundant; Inadequate number of fire extinguishers; Non-functional firefighting system; Insufficient ducts.	25
2020	Short circuit in AC / in ventilator / in ICU ward / in generator and generator overheating Batteries caught fire in server room at basement	No fire signs displayed; Sprinkler system not installed Staff not trained in fire safety; Fire doors not constructed to standard; Illegal construction; Fire NOC not obtained.	14
2019	Short circuit in oxygen pipeline connected to radiant warmer / in refrigerator / in ventilator in CCU / due to leakage in oxygen supply pipe behind manifold / in AC / in water heater in recovery room / in battery room near ICU	Circuit breaker not installed; No fire safety alarm; Lack of ventilation; Insufficient road space for fire tender; NOC not obtained; Firefighting equipment not installed; Occupancy cert. and Fire clearance cert. not obtained.	2
2018	Short circuit in refrigerator in Laboratory / in air conditioner / in AC / in ICU ward Overheating of chemicals	Sprinkler and fire detection system not operational; Fire NOC not obtained.	10
2017	Fire started in AC vent Short circuit in UPS in reception area / in store room / in AC in operation theater	Fire NOC not obtained; Fire alarm and water sprinklers not functional; No emergency evacuation plan; Mock drills not conducted.	N/A
2016	Short circuit in air conditioner Chemical reaction in laboratory basement	Fire NOC not obtained; Main emergency exit gate locked; LPG cylinders stored in the basement.	72
2015	Short circuit in AC in the ICU / in dialysis operating theater	Firefighting equipment not functioning properly.	1
2014	No information available	No information available.	N/A
2013	Short circuit in meter box / due to faulty electric wires in nursery ward	Old and faulty electric wires without insulation.	1
2012	Short circuit in electric box / in store room	Illegal construction of fourth floor.	N/A
2011	Flammable materials caught fire in basement due to electric shock	Illegal storage of flammable material in the basement; Fire extinguishers and sprinkler systems not working.	90
2010	Short circuit in electronic box	No emergency available.	2

Table 2. Fire incidents in hospitals in Thailand

Years	Number of Fire Incidents
2023	3
2022	4
2021	2
2020	6
2019	4
2018	5
2017	7
2016	4

2. METHODOLOGY

The purpose of this research is to develop a prototype of fire risk assessment model for hospital buildings in urban areas. It started from collecting relevant information and interviewing 8 specialists who specialize in occupational health and safety, fire control and prevention system and hospital buildings. Then, prepare a draft of a fire risk assessment model and form for hospital buildings in urban areas by utilizing applied principles from NFPA 551 Guide for the Evaluation of Fire Risk Assessments [8] and OHSAS 18001: 2007 Occupational Health and Safety Management System [9]. They consist of 4 steps: (1) Hazard identification and fire opportunity hazard assessments which have the related laws of fire prevention and control systems [4, 5], NFPA 101 The Life Safety Code standard [10], NFPA 99 Health Care Facilities Code [11], safety standards in hospitals such as HA Hospital Accreditation [12], JCI Joint Commission International [13] and related standards of fire prevention and control systems according to Engineering Institute of Thailand [14-16]. They consist of 4 categories: Sources of fire, people at risk, fire and life safety and fire protection management; (2) Hazard severity assessment which have the related forms developed from NFPA 551 [8] and OHSAS 18001 [9]; (3) Fire risk levels assessment which have the related forms developed from NFPA 551 [8] and OHSAS 18001 [9]; (4) Fire risk management of hospital buildings in urban areas which have the related forms developed from NFPA 551 [8] and OHSAS 18001 [9].

Eighteen experts in occupational health and safety, fire control and prevention, and hospital buildings examined the draft model and related forms for fire risk assessment of hospital buildings in urban areas. The draft model and forms were then applied to a hypothetical situation. Following this, a brainstorming meeting was held to review and refine the draft model and forms. Based on expert feedback, the researcher developed a revised draft of the model and forms for fire risk assessment. Finally, Flander's criteria (Flander, 1989) were used to assess consistency at 60% level, as determined by specialists, resulting in a more accurate and complete final draft.

This research was approved by the Human Research Ethics Review Committee, Faculty of Medicine Vajira Hospital Navamindradhiraj University, Certification document number 016-2566. Information from research will be confidential. The research report will be presented only with an overview related to the research. Unrelated information will not be disclosed to the public.

3. RESULTS

3.1 Steps of fire risk assessment model for hospital building in urban areas

As this is the initial phase, the model will be piloted with experts to refine and optimize it for practical use, the prototype fire risk assessment model for hospital building in urban areas consists of four main steps.

Step 1: Fire hazard identification and fire opportunity hazard assessment

This was newly developed based on related fire prevention and control laws [4, 5], NFPA 101 The Life Safety Code standard [10], NFPA 99 Health Care Facilities Code [11], hospitals safety standards such as HA Hospital Accreditation [12], JCI Joint Commission International [13] and related standards from Engineering Institute of Thailand [14-16]. This step includes four categories with specific items for identifying hazards.

Category 1: Identification of fire hazards includes three main items. Item 1: Source of ignition (5 questions), item 2: Source of fuel (2 questions), and item 3: Source of oxygen (2 questions). Total: 9 questions, 27 scores.

Category 2: Identification of people at risk includes one main item. Item4: Persons who will be harmed by fire (2 questions). Total: 2 questions, 6 scores.

Category 3: Fire and life safety includes five main items. Item 5: Fire escape preparation (8 questions), item 6: Fire protection system (3 questions), item 7: Fire detection and fire alarm (4 questions), item 8: Firefighting preparation (2 questions). Total: 17 questions, 51 scores.

Category 4: Fire protection management includes two main items. Item 9: Fire response (9 questions), item 10: Management of work that causes sparks from outsiders (2 questions). Total: 11 questions, 33 scores.

Scoring considers the chance of a fire occurring individually. There are three levels of chance: Level 1 (low chance, score 1), Level 2 (medium chance, score 2) and Level 3 (high chance, score 3). Irrelevant items are assigned a score of zero. For example, category 1, item 1.1: such as work procedures, operator training, inspections, warning signs, fire extinguishers, designated work areas, and personal protective equipment are in place, the fire occurrence opportunity is categorized as level 1 (score 1).

Then, the obtained scores from all 39 questions across all categories total 117 points. Irrelevant items are discarded. The comparison of the obtained scores is calculated as percentages using the formula "(Obtained score * 100)/Total score". If the total score is less than 50, the fire opportunity is considered as "Little opportunity level" with minimal impact on building occupants. Spread of fire does not affect building users or residents to be injured or death. If the total score is between 50 to 70, the fire opportunity is considered as "Moderate opportunity level" with potential for minor injuries to a few occupants. Spread of fire affects a small number of building users or residents to be slightly injured but not death. If the total score exceeds 70, the fire opportunity will be considered as "High opportunity level" with a risk of severe fire spread and fatalities. Details are shown in Tables 3 and 4.

Step 2: Fire severity assessment

Fire severity assessment is considered from fire hazard levels. Severity levels are categorized as low, moderate, and high, based on NFPA 551 [8] and OHSAS 18001 [9].

Level 1: Little severity; Minimal fire spread with no impact

on occupants, building structure, or property damage exceeding 5,000 baht.

Level 2: Moderate severity; Fire spread affecting a few occupants with minor injuries, building damage requiring repairs, and property loss between 5,000 and 100,000 baht.

Table 3. Fire hazard identification and fire opportunities hazard assessment for hospital buildings in urban areas

	List	Opportunity Level			
		None=0	Little=1	Moderate=2	High=3
	Category 1: Identify Fire Hazards				
1.	**Source of ignition**				
1.1	Are there safety measures in place to control activities involving open flames, such as incense sticks, candle, alcohol lamps, gas stoves, pendants, and lasers?				
1.2	Are there safety measures in place to control activities generating heat such as cooking, heating pads, boilers, electric stoves, induction cookers, steamers, gas dryers, microwaves, hot water bottles, and ironing clothes?				
1.3	Are there designated area for charging electrical devices like staff and service user mobile phones?				
1.4	Are there safety measures in place to control the use of electrical equipment, medical equipment, small appliances, and batteries that are damaged or not used according to manufacturer instructions, including proper electrical connections and adapter usage?				
1.5	Are there safety measures in place to control the use of damaged power cords and receptacle?				
2	**Source of fuel**				
2.1	Are there safety measures in place to control the usage and storage of flammable substances such as thinner, alcohol, fuel and flammable gas in the areas?				
2.2	Are there safety measures in place to control the usage and storage of combustible substances such as cotton wool, plastic, rubber, foam, paper, rags, scrap wood, permanent furniture, building decorations, wallpaper and notice boards in the areas?				
3	**Source of oxygen**				
3.1	Are there safety measures in place to control the storage of oxygen such as oxidizing chemicals, oxygen tanks or local medical gas piping line systems?				
3.2	Are there safety measures in place to control activities that use oxygen for treatment?				
	Category 2: Identify Person at Risk				
4	**People at risk by fire**				
4.1	Are there any irrelevant personnel, outsider, or individuals with limited self-care abilities, children aged between 7-12 years, or person who cannot help themselves including children between 0-6 years in examined areas?				
4.2	Are there safety measures in place to help the person according to section 4.1.				
	Category 3: Fire and Life Safety				
Passive Fire Protection					
5	**Fire escape preparation**				
5.1	Are there safety measures in place to control fire escape routes (occupant load and egress capacity)?				
5.2	Are there safety measures in place to control fire exit doors?				
5.3	Are there safety measures in place to control fire escape stairs?				
5.4	Are there safety measures in place to control exits and fire escapes signs?				
5.5	Are there safety measures in place to control emergency lighting and battery-type?				
5.6	Are there safety measures in place to control backup lighting: Emergency power generator?				
5.7	Are there safety measures in place to control evacuation or emergency elevators?				
5.8	Are there safety measures to control fire extinguishing elevators? (Note: Not required for buildings built before 1992)				
6	**Fire protection system**				
6.1	Are there safety measures in place to ensure the building structure's strength, fire walls and fire doors?				
6.2	Are there safety measures in place to control the building's enclosure systems, and fire compartments?				
6.3	Are there safety measures in place to control the smoke ventilation system, compressed air systems and spread smoke?				
Active Fire Protection					
7	**Fire detection and fire alarm**				
7.1	Are there safety measures in place to control fire detection system equipment such as smoke or heat detector?				
7.2	Are there safety measures in place to control the fire alarm systems, including manual fire alarms, control cabinets, and warning devices?				
7.3	Are there safety measures in place for automatic fire extinguishing systems such as fire sprinkler system?				
7.4	Are there safety measures in place for automatic fire extinguishing systems such as clean agent?				

	List	Opportunity Level			
		None=0	Little=1	Moderate=2	High=3
8	**Firefighting preparation**				
8.1	Are there safety measures in place to ensure fire extinguishers are effective and appropriate for different type of fire?				
8.2	Are there safety measures in place to control hoses with nozzle and hydrant?				
	Category 4: Fire Protection Management				
9	**Fire response preparation**				
9.1	Are there prevention manual and evacuation plan in place both the organizational and unit levels?				
9.2	Are there rehabilitation plans or plans for referring patients to other hospitals?				
9.3	Are there training plan for responding and evacuation for both day and the night shift at the organizational and unit levels?				
9.4	Is there designated person responsible for implementing the fire prevention manual and evacuation plan?				
9.5	Are there trainings programs for personnel on rescue and evacuation procedure?				
9.6	Are there basic firefighting trainings programs for personnel?				
9.7	Is there appropriate equipment for evacuating patients?				
9.8	Is there firefighting team equipped with necessary firefighting equipment in the buildings?				
9.9	Are there annual fire response and fire evacuation drills conducted?				
10	**Management of activity that caused sparks from external sources**				
10.1	Are there safety measures inplace to control hotwork activities such as welding and cutting from external sources?				
10.2	Are there safety measures inplace to control hotwork permit system?				

Table 4. Fire opportunity level of hospital buildings in urban areas

Percentage of Calculated Scores	Fire Opportunity Level	Description
Less than 50	Little (1)	Fire does not spread, posing no risk of injury or death to occupants or residents.
50-70	Moderate (2)	Fire spreads minimally, posing a risk of minor injuries to a few occupants but no fatalities.
More than 70	High (3)	Severe fire spread with potential fatalities can occur.

Level 3: High severity; Extensive fire spread with severe occupant impact, significant building damage, and property loss exceeding 100,000 baht.

Fire severity considers overall area conditions, unlike fire opportunity assessed individually as shown in Table 2. Detailed fire severity assessment criteria for urban hospital buildings are in Table 5.

Table 5. Fire severity assessment for hospital buildings in urban areas

Fire Severity Level	Description
Little (1)	Minimal fire spread with no impact on occupants, building structure, or property damage exceeding 5,000 baht.
Moderate (2)	Fire spread affecting a few occupants with minor injuries, building damage requiring repairs, and property loss between 5,000 and 100,000 baht.
High (3)	Extensive fire spread with severe occupant impact, significant building damage, and property loss exceeding 100,000 baht.

Step 3: Fire risk level assessment

The evaluation of the fire risk level for a hospital building in an urban area involves considering the assessment results from both the fire hazard opportunity and severity, as derived from Tables 4 and 5. This process helps determine at what level the building's fire risk should be categorized. The fire risk level of hospital building in urban areas are divided into five levels: unacceptable, high, moderate, acceptable, and little, based on NFPA 551 [8] and OHSAS 18001: 2007 [9], which can be specified as:

Little level: A score is 1, resulting from a little level in both opportunity and severity score as 1.

Acceptable level: A score is 2, resulting from either a little level in an opportunity score as 1 and a moderate level in a severity score as 2, or a moderate level in an opportunity score as 2 and a little level in severity score as 1.

Moderate level: A score is 3, resulting from either a little level in opportunity score as 1 and a high level in severity score as 3, or a high level in opportunity score as 3 and a little level of severity score as 1. A moderate level can also be a score of 4, resulting from a moderate level in both opportunity and severity score as 2.

High level: A scores is 6, resulting from either a moderate level in an opportunity score as 2 and a high level in severity score as 3, or a high level in an opportunity score as 3 and a moderate level in a severity score as 2.

Unacceptable level: A scores is 9, resulting from a high level in both opportunity and severity score as 3.

Details are shown in Table 6.

Table 6. Fire risk assessment level for urban hospital buildings

Severity / Opportunity	High (3)	Moderate (2)	Little (1)
High (3)	Unacceptable (9)	High (6)	Moderate (3)
Moderate (2)	High (6)	Moderate (4)	Acceptable (2)
Little (1)	Moderate (3)	Acceptable (2)	Little (1)

Step 4 : Fire risk management of hospital buildings in urban areas

The results of the fire risk assessment level from Table 6 are used to create the fire risk management guidelines for hospital building in urban areas, referring to NFPA 551 [8] and OHSAS 18001: 2007 [9]. The risk management is identified as:

Unacceptable level: In the fire risk practical guidelines, work is not allowed to begin or continue unless the fire risk level is reduced. If the fire risk level cannot be reduced, work must be stopped.

High level of fire risk: In the fire risk practical guideline, work is allowed to begin or continue only when the fire risk level is reduced. Sufficient resources and measures must be allocated to reduce that fire risk. Any fire risk in the activity or area must be addressed urgently.

Moderate level: In the fire risk practical guideline, a method to reduce the fire risk level must be identified, and the cost of protection should be carefully considered within a specified budget. Measures to reduce the fire risk should be ready within the specified timeframe. If the moderate fire risk level is associated with serious damage, further evaluation should be conducted to determine the more accurate probability of damage and decide if additional controls are necessary.

Acceptable level: In the fire risk practical guideline, no additional controls are required. Consideration of further risk reduction may be made if worthwhile and cost-effective. Frequent monitoring is still required to ensure that existing controls are consistently maintained.

Little level: In the fire risk practical guidelines, no additional actions are required.

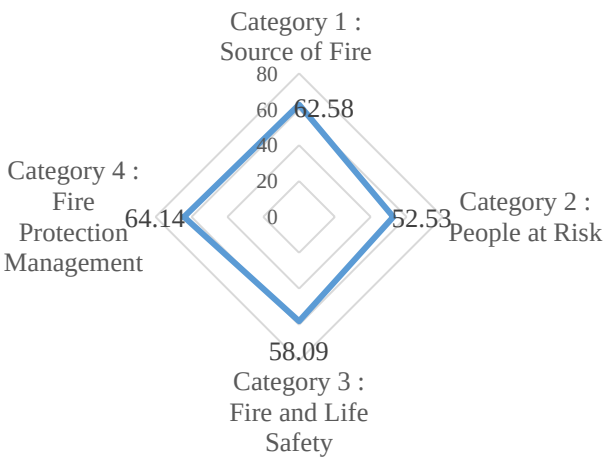

Figure 1. Fire risk assessment scores of hospital buildings in urban areas

3.2 Results of prototype fire risk assessment model for hospital building in urban areas test

Results from 18 experts on fire risk assessment of hospitals in urban areas with the given hypothetical situation was found as Figure 1. Opportunities for fire were categorized as follow: Category 4: Fire Protection Management has the highest risk assessment score at 64.14%, followed by Category 1: Source of Fire at 62.58%, Category 3: Fire and Life Safety at 58%, and Category 2: People at Risk at 52.53%. The opportunities were calculated using the equation (score obtained *100)/total score, resulting in a value of 59.85, which is considered "Moderate". Severity of fire is "High". This means that spread of fire and the amount of flammable substance severely impact occupants in a particular building, leading to disability or death. The building structure is severely damaged and is unlikely to be restored to a normal condition. Damaged properties are worth more than 100,000 baht. The evaluation of fire risk level is "High"; therefore, safety management must reduce the risk before starting work.

4. DISCUSSIONS

Fire risk management of hospital buildings in urban areas covers of sources of fire, people at risk from fire, fire and life safety and fire protection management. These principles differ somewhat from NFPA 551 [8]. The process of identifying fire hazards in hospital building specifies the fire opportunity in item by item to determine the likelihood of fire in each area. The severity of fire is assessed holistically for each area, as individual fire severities are generally consistent. The levels of opportunity and severity of fire risk assessment levels and management adhere to the guidelines of OHSAS 18001 [9].

Fire hazard identification and fire opportunity assessment forms for hospital building in urban area will follow the principles of related fire prevention and control laws [4, 5], NFPA 101 [10], NFPA 99 [11], safety standards in hospitals such as Hospital Accreditation [12] and Joint Commission International [13] and related standards of fire prevention and control systems according to Engineering Institute of Thailand [14-16]. It covers general data of inspected areas, which are classified into four distinct categories; Category 1: Fire hazards, Category 2: People at risk by fire, Category 3: Fire and life safety, and Category 4: Fire protection management. Additionally, other factors should be considered, but they are not used as a criteria for consideration in the fire risk assessment of hospital buildings in urban areas. This is due to high variation or inability to clearly specify certain information when addressing questions such as: characteristics of buildings and urban space, socioeconomic, demographic, education, human and organization aspects, history of fire equipment, climate factors, unit information and other life information [17, 18], construction or renovation in areas of the hospital on the date of fire, the actual location of the fire, the number of persons in the area on a date of fire, traffic conditions around the fire location, access to the area by emergency control teams (including personnel, fire trucks, ambulances, water trucks, cable cars etc.), firefighting and rescue equipment of external fire departments (such as lift trucks, special equipment etc.), and fire expert personnel both inside and outside the hospitals. Therefore, these factors should be considered to understand actual fire opportunities.

Fire risk assessment model for hospital buildings in urban areas are designed to be applicable to both public and private hospitals that are either already certified or in the process of certification under HA and JCI standard. Because the various standard systems that hospitals follow are guidelines for reducing the risk or severity of fire, once a fire risk assessment is conducted, the obtained score will indicate the operational results, areas for improvement, or, if any standards have not yet been certified, the obtained scores can still be used as a guideline for takeing action regarding fire risk levels and operations. Hospitals are particularly at risk of fire due to the usage and storage of fuel and lack of understanding of non-

smoking areas. The results of the study conclude that although hospitals meet JCI certification standards and comply with the law, it is crucial to have measures to correct, improve, raise awareness and understanding of fire prevention and suppression plans, as well as proper fire evacuation plan [19].

Presentation of likelihood of fire using a diagram will help to clearly understand the causes and solutions. Risk mapping will assist communication and socialization with related stakeholders. The mapping result, with special information, can assist in determining the program to control the hazard source effectively and efficiently [20].

In addition to following the guidelines based on the risk assessment levels, risk management should also consider other factors such as fire safety stakeholders practice system, fire safety action plan and fire risk management. These were identified as the three main variables that promote fire safety program [21].

Fire risk assessments in hospitals can be conducted using various methods, such as FMEA Combined with multi-criteria decision making methods [22] or fire risk assessment method for engineering (FRAME) [23-25], which are typically desk-based assessments. However, the risk assessment method developed by the researcher requires on-site inspections. Therefore, users should carefully consider the most suitable method based on their specific objectives.

5. CONCLUSIONS

The developed prototype of a fire risk assessment model for urban hospital buildings has been successfully tested by experts. Following the prescribed risk assessment steps, which include 1) Hazard identification and fire opportunity assessments, 2) Fire severity assessment, 3) Fire risk level assessment, and 4) Fire risk management, the model has demonstrated its ability to effectively identify potential fire hazards in hospital buildings and assess their associated risks. The results which are aligned with the guidelines set forth in NFPA 501 and other relevant laws and standards. Additionally, the model can provide targeted solutions to address identified issues.

As this fire risk assessment model for hospital buildings in urban areas is still in the prototype stage, applying this prototype to inspect hospital buildings and implementing the indicated corrective actions can effectively reduce the likelihood and severity of fires in hospital buildings in urban areas.

Future development should focus on creating a user-friendly software application. This application should be adaptable to various on-site assessment environments and capable of generating trends and statistics on past fire risk assessments of urban hospitals.

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