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Article

Application of Analytic Hierarchy Process to Rank Fire Safety Factors for Assessing the Fire Probabilistic Risk in School for the Blind Building

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Abstract: Fires are the leading cause of death, serious injury and property damage. In the past, schools, temples and government offices had more frequent fires than they should. Statistics showed that the number of fires between 2017 to 2022 amounted 13,593 cases which mostly occurred in the school, temple and government offices (40.0% of all buildings). Moreover, it causes more damage among disabled especially the blinds who has a limited vision. Therefore, this cross-sectional purpose of this study was to assess fire risk including management model in school for the blind. The fire checklists, brainstorming and Analytic Hierarchy Process (AHP) were applied to estimate the fire risk in school for the blind building. The findings revealed an inherent fire hazard factors with a risk score equal to 3.2830 and evacuation factors with a risk score equal to 3.3178 were acceptable risk except the fire control factors with a risk score equal to 1.4320 was unacceptable risk may cause an impact on life, health, property and public communities. Eventually, efforts should be made to supervise those risk factors by designing suitable activities to reduce undesirable conditions in school for the blind.

Keywords: fire probabilistic risk; fire safety factor; fire checklist; analytic hierarchy process

1. Introduction

Fires in Thailand tend to happen more frequently and severely mainly because of unsafe acts and unsafe conditions. For megacity with a high permanent and temporary population like Bangkok, fire management becomes more crucial. Fires may cause many injuries and casualties as well as damage to property and assets, let alone harm to the overall economic system. Department of Disaster Prevention and Mitigation, Ministry of Interior of Thailand [1], as the administrative body responsible for the city, undertakes the mission to protect population from public disasters and make life safer, report the number of fires between 2017 to 2022 amounted 13,593 cases which mainly occurred in the school, temple and government offices (40% of all buildings). Moreover, it causes more damage among disabled especially the blinds who has a limited vision.

Previous studies in the fire probabilistic risk assessment sector has predicted the risk status in the building where has the occupants to able the fire evacuation when fire occurred such as Prashant A/L Tharmarajan [2] studied on the essential aspects of fire safety management in high-rise buildings, John A. Moore and M. Phil [3] conducted a study on the assessment of fire safety and evacuation assessment in nursing home, Yeung Cho Hung [4] was to study on fire safety management of public rental housing in Hong Kong, Tanima Abdul Wahed [5] was to focus on impact of facility management on fire safety crisis in industry. There is also a study by Ayyappa Thejus Mohan [6] focused on risk acceptance in fire safety engineering. All above research focused on the fire probabilistic risk assessment and management in different buildings but there is no focus on a new tool used for calculating the level of risk. It obviously can be seen that there is still a lack of reliable assessment tool for fire safety. This is an important thing to ensure the safety of occupants in the building especially blind people who have limited vision. Assessing the fire risk is important in occupational health and safety. Therefore, this study aimed to assess fire risk including management model in school for the blind building including applying fire probabilistic risk assessment technique using the checklist method, which is a hazard identification technique used to reduce failure by compensating for potential limits of human memory and attention. It helps to ensure consistency and completeness in carrying out a task. This technique examines fire hazards according to laws and standards and therefore appropriate and consistent with the task of applying it for risk assessment as compared to other techniques. However, the checklist has limitations in determining the probability of the event, which sometimes some fire safety factors are unable to determine these values. Therefore, it is necessary to apply other techniques to determine the probability of events. The Analytic Hierarchy Process (AHP) proposed by Thomas Saaty [7] is a versatile tool for dealing with complex decision-making problems. It is a hierarchical structure of goals, objectives, main criteria, sub-criteria, and alternative. The AHP assists deciders look for one the best matches for their goal by eliminating biased decision. It provides an extensive and methodical structure for construction a decision issue, for illustrating and estimating its elements, for implicating those elements to overall goals, and for assessing alternative solutions. This study eventually has applied an AHP to determine the relative weight of each fire hazard factors from checklist and to determine the probabilistic risk of fire. It also proposed measures for managing the fire risk in school for the blind building.

2. Materials and Methods

2.1. Study design and setting

A cross-sectional study was conducted between June and December 2022 in school for the blind building in Bangkok, Thailand. The study area was a classroom of a blind school building according to the Building Act, B.E. 2522 of Thailand. This classroom is ventilated air natural. There are three stories layer, 79.5 m. long, 16 m. wide and 3 m. high as shown in Figure 1. In this study, the classroom was selected by considering the prioritization of fire safety problems, namely attention to problem of staffs, attention of management to problem solving and problem size.

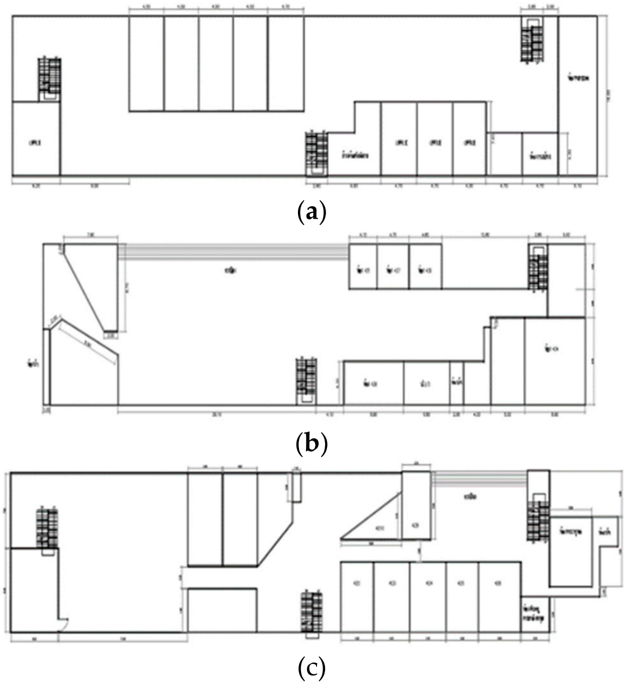

Figure 1. School for the blind building floor plan: (a) The first-floor plan; (b) The second-floor plan; (c) The third-floor plan.

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2.2. Instrument development

An instrument for data collection consisted of checklist and using Expert Choice Version 11 in computing the relative weight from an AHP structure and to determine the risk of fire in school for the blind building.

Expert Choice software for cooperative decision-making solution that is based on multi-criteria decision making. This software helps organizations make better decisions and manage risk with speed, transparency and alignment. Expert Choice implements the AHP [8] and has been used in fields such as manufacturing, [9] environmental management, [10,11] shipbuilding [12] and agriculture [13]. This collaboration software was created by Thomas Saaty and Ernest Forman in 1983 [14] and supplied by Expert Choice Corporation. This research used this tool to compute the relative weight by brainstorming from the checklist. The AHP provided a structural framework as shown in Figure 2 for setting priorities on each level of the hierarchy using pairwise comparisons that were quantified using 1-9 scale in Table 1. The pairwise comparisons between the m decision criteria can be conducted by asking fire safety experts' questions. The answers to those questions of m×m pairwise comparison matrix was stated as follows in Equation (1).

$$A = (a_{ij})_{m\times m} = \begin{matrix} C_1 \\ C_2 \\ \vdots \\ C_m \end{matrix} \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & \vdots & \cdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \quad (1)$$

where a_{ij} denoted a numerical judgment on w_i/w_j with $a_{ii}=1$ and $a_{ij}=1/a_{ji}$ for i,j=1, … ,m. On condition that the pairwise comparison matrix $A=(a_{ij})_{m\times m}$ fulfilled $a_{ij}=a_{ik}\,a_{kj}$ for any i,j,k=1, … ,m, afterwards A is said to be magnificently consistent; differently it was said to be inconsistent. The pairwise comparison matrix A, the weight vector W can be computed by solving as follows in Equation (2).

$$AW = \lambda_{\max} W \quad (2)$$

where $\lambda_{\max}$ is the maximum eigenvalue of A. The answers from experts may be incompetent to contribute ideally accordant pairwise comparisons, it was dictated that the pairwise comparison matrix A must be an acceptable consistency, which can be examined by the following consistency ratio (C.R.), as expressed in Equation (3).

$$C.R. = \frac{(\lambda_{\max} - n)/(n-1)}{RI} \quad (3)$$

where RI is a random inconsistency index, those values were deviated with the order of pairwise comparison matrix. The RI values for the pairwise comparison matrices with the order from 1 to 10 was shown in Table 2. Whether or not C.R.≤0.1, the pairwise comparison matrix was considered to have an acceptable consistency; on the other hand, it must be corrected.

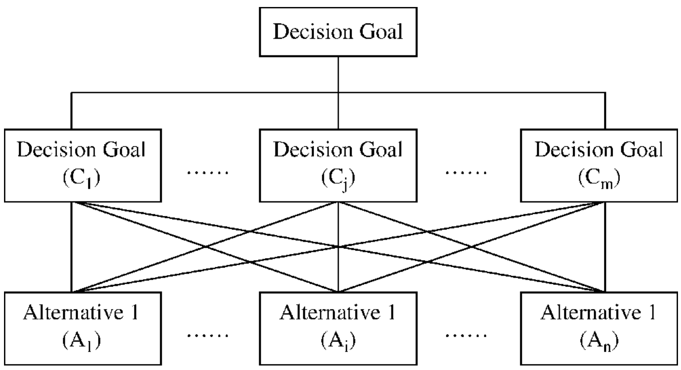

Figure 2. A three-level decision hierarchy.

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Table 1. Numerical value pairwise comparison scale [7].

Numerical rating	Description for risk factor evaluation
1	Equivalently
2	Equivalently to neutrally more
3	Neutrally more
4	Neutrally to greatly more
5	Greatly more
6	Greatly to very greatly more
7	Very greatly more
8	Very greatly to extremely more
9	Extremely more

Table 2. Random inconsistency index for pairwise comparison matrices [7].

Order (n)	Random inconsistency index (RI)
1	0
2	0
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Decision alternatives can be considered pairwise with regard to each decision criterion. After the weights of decision criteria and the weights of decision alternatives were achieved by using pairwise comparison matrices, the overall weight of each decision alternative with regard to the decision goal can be produced by following addition weighting method [7], as expressed in Equation (4).

$$w_{Ai} = \sum_{j=1}^{m} w_{ij} w_j, i = 1,..., n, \tag{4}$$

where w_j (j=1,...,m) are the weights of decision criteria, w_{ij} (i=1, … ,n) are the weights of decision alternatives with regard to criterion j, and w_{Ai} (i=1, … ,n) are the overall weights of decision alternatives. The best decision alternative is the one that has the greatest overall weight relative to the decision goal.

Expert Choice implemented the AHP was used for computing the relative weight instead of calculating by hand according to Equations (1) to (4).

2.3. Order of operations steps

There were three different stages of the research process. The purpose of the first stage was to identify the fire risk using the fire checklist. This contextual information was then used in the second stage of the research for fire probabilistic risk assessment using analytic hierarchy process and brainstorming for obtaining the weight of each factors. Last stage, the results were finally compiled the fire risk scores into a decision for conducting the fire management model to solve the problems in order to reduce the fire risk in school for the blind building. An order of operation steps was shown in Figure 3.

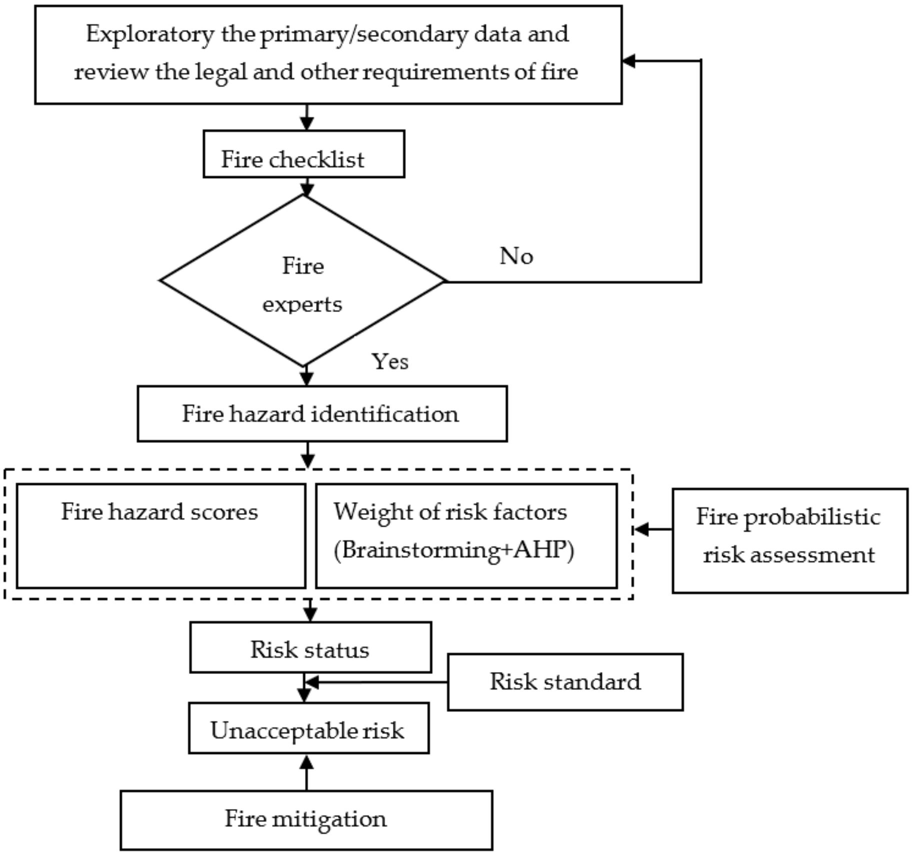

Figure 3. Order of operation steps.

First stage: exploratory the primary and secondary data for design the fire checklist. Exploratory the primary and secondary data including review the legal and other requirements of fire for design the fire checklist. This fire checklist was then taken to give the fire experts. The fire checklist was used to collect data for identifying the hazard in school for the blind building.

Second stage: fire probabilistic risk assessment. Quantifying the risk of the common tasks with consideration of probability and relative weight of fire safety factors. Fire probabilistic risk assessment using the brainstorming and analytic hierarchy process for obtaining the weight of each factors in the fire checklist.

Third stage: fire probabilistic risk scores into a decision for conducting the fire mitigation. The results from the stage of quantification of fire probabilistic risk assessment were compiled the fire risk scores to compared with risk standard. Finally, unacceptable risk has to conduct the fire mitigation to solve the problems in order to reduce the fire risk in school for the blind building.

Fire probabilistic risk assessment in school for the blind building can be calculated in the Equation 5. The results of fire probabilistic risk assessment were shown in the Tables 3–5.

$$R = \sum_{i=1}^{n} P_{ci} \times W_{ci} \tag{5}$$

R = Fire probabilistic risk score

n = The number of fire probabilistic risk assessment index

W_{ci} = Weight of fire probabilistic risk assessment indicator i, the range is 0 to 1

P_{ci} = Score of fire probabilistic risk assessment indicator i, the value is an integer between is 1 to 5.

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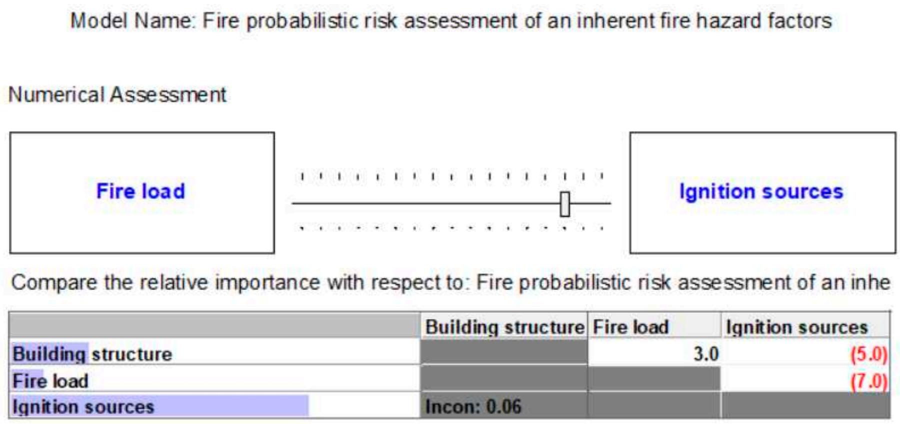
Table 3. The meaning and score of fire probabilistic risk [15].

Score	Description
1	Remote possibility
2	Possible but not possibility
3	Moderately possibility
4	Important possibility
5	Most possibility

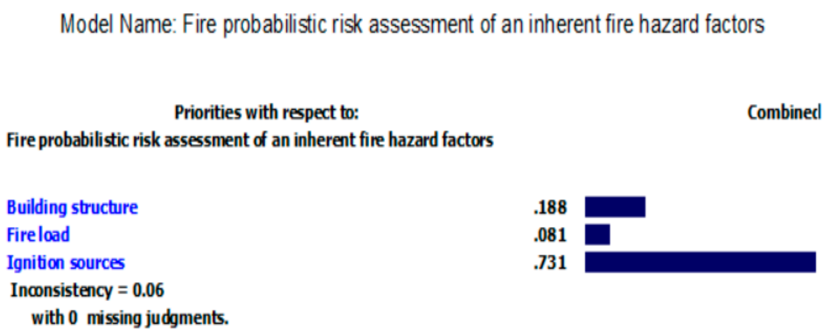
The fire risk score was considered in two elements. Namely, the assessment grade scores were based on brainstorming and with meaning that the probability level was remote possibility (Score=5), possible but not possibility (Score=4), moderately possibility (Score=3), important possibility (Score=2), and most possibility (Score=1), respectively. The scores of fire probabilistic risk assessment were shown in Table 3 and relative weights of fire probabilistic risk assessment indicator were obtained from the calculation by Expert Choice V.11. The probabilistic risk assessment was performed in Equation (5) and unacceptable risk level (score less than 2.5) requires further mitigation measures.

3. Results

Assessment the scores were based on brainstorming from fire experts. Expert Choice V.11 implemented the AHP for computing the relative weight each fire safety factors. The results were shown in Figures 4–6 and Tables 4–6.



(a)



(b)

Figure 4. Pairwise comparisons of an inherent fire hazard factors: (a) Pairwise comparisons in Expert Choice V.11 program.; (b) Relative weight calculation using Expert Choice V.11 program.

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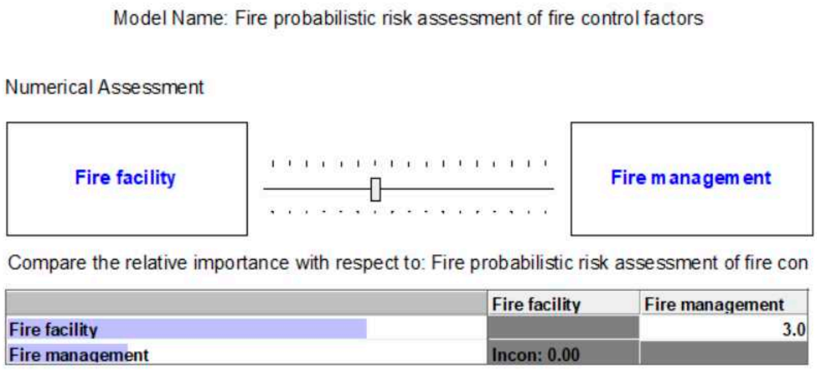

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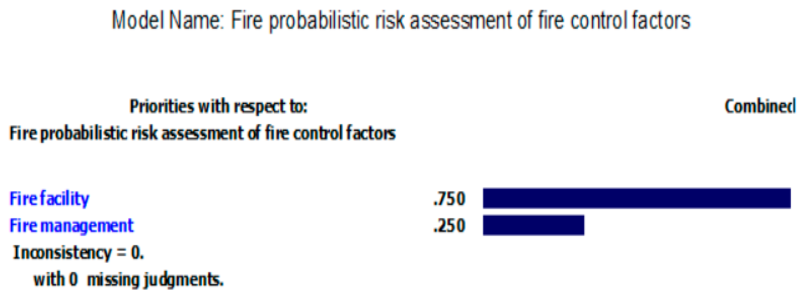
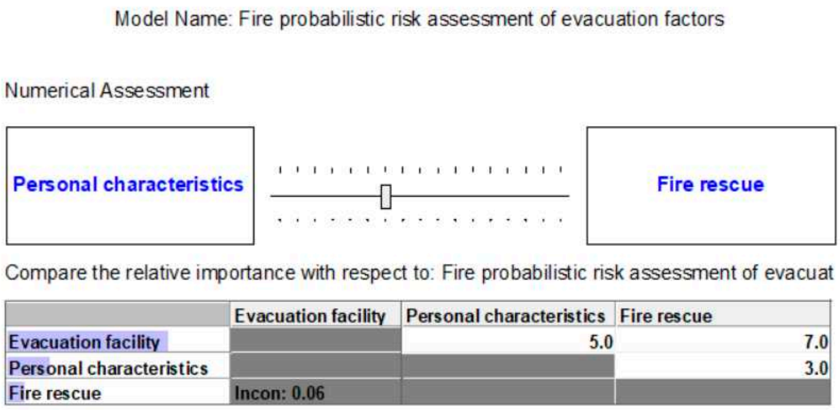
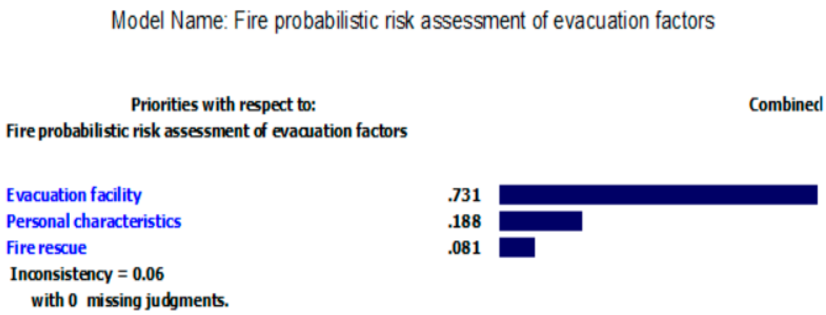


(b)

Figure 5. Pairwise comparisons of fire control factors: (a) Pairwise comparisons in Expert Choice V.11 program.; (b) Relative weight calculation using Expert Choice V.11 program.



(a)



(b)

Figure 6. Pairwise comparisons of evacuation factors: (a) Pairwise comparisons in Expert Choice V.11 program.; (b) Relative weight calculation using Expert Choice V.11 program.

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Table 4. Fire probabilistic risk assessment of an inherent fire hazard factors.

Criteria	Inherent fire hazard factors	Grade assessment (A)	Weighting attribute (B)	Score attribute (A x B)
		Building structure		
1	Height of the blind school building	4	0.0625	0.2500
2	Multilayer	4	0.1375	0.5500
3	Fire resistance rating	3	0.3250	0.9750
4	Hazard classification	1	0.4750	0.4750
	Sum of A x B		(C)	2.2500
	Relative weight of building structure		(D)	0.1880
	Building structure scores		(C) x (D)	0.4230
		Fire load		
1	Location area	3	0.1700	0.5100
2	Interior decoration	3	0.8300	2.4900
	Sum of A x B		(C)	3.0000
	Relative weight of fire load		(D)	0.0810
	Fire load scores		(C) x (D)	0.2430
		Ignition sources		
1	Electrical equipment	3	0.6330	1.8990
2	Type of combustible gas supply	3	0.1070	0.3210
3	External fire	5	0.6330	1.3600
	Sum of A x B		(C)	3.5800
	Relative weight of ignition sources		(D)	0.7310
	Ignition sources scores		(C) x (D)	2.6170
	Building structure scores + Fire load scores + Ignition sources scores			3.2830

Table 5. Fire probabilistic risk assessment of fire control factors.

Criteria	Fire control factors	Grade assessment (A)	Weighting attribute (B)	Score attribute (A x B)
		Fire facility		
1	Fire alarm and fire control linkage system	1	0.3520	0.3520
2	Portable fire extinguisher	3	0.2020	0.6060
3	Floor plan	1	0.0930	0.0930
4	Safety sign	1	0.1780	0.1780
5	Emergency lighting	1	0.1320	0.1320
6	Lightning protection system	5	0.0430	0.2150
	Sum of A x B		(C)	1.5760
	Relative weight of fire facility		(D)	0.7500
	Fire facility scores		(C) x (D)	1.1820
		Fire management		
1	Fire safety inspection	1	0.5400	0.5400
2	Basic fire fighting	1	0.2300	0.2300
3	Fire drill	1	0.0725	0.0725
4	Fire emergency plan	1	0.1575	0.1575
	Sum of A x B		(C)	1.0000

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Relative weight of fire management	(D)	0.2500
Fire management scores	(C) x (D)	0.2500
Fire facility scores + Fire management scores		1.4320

Table 6. Fire probabilistic risk assessment of evacuation factors.

Criteria	Evacuation factors	Grade assessment (A)	Weighting attribute (B)	Score attribute (A x B)
		Evacuation facility		
1	Indoor fire exit stair	5	0.1300	0.6500
2	Fire exit door	2	0.1040	0.2080
3	Fire exit discharge	1	0.0830	0.0830
4	Emergency radio	3	0.0390	0.1170
5	Capacity of means of egress	4	0.4540	1.8160
6	Dead end corridors	5	0.1630	0.1630
7	Escape equipment	1	0.0270	0.0270
	Sum of A x B		(C)	3.0640
	Relative weight of evacuation facility		(D)	0.7310
	Evacuation facility scores		(C) x (D)	2.2398
		Personal characteristics		
1	Crowd density	3	0.1400	0.4200
2	Number of blind students per teacher	5	0.2900	1.4500
3	Degree of familiarity with building	3	0.5700	1.7100
	Sum of A x B		(C)	3.5800
	Relative weight of personal characteristics		(D)	0.1880
	Personal characteristics scores		(C) x (D)	0.6730
		Fire rescue		
1	Distance from fire brigade	5	0.5730	2.865
2	Distance from hospital	5	0.1400	0.700
3	First aid kit	5	0.2870	1.435
	Sum of A x B		(C)	5.000
	Relative weight of fire rescue		(D)	0.081
	Fire rescue scores		(C) x (D)	0.4050
	Evacuation facility + Personal characteristics + Fire rescue			3.3178

All fire safety factors from Expert Choice V.11 showed the value of Consistency Ratio (C.R.) less than 0.1, the pairwise comparison matrix was assumed to have an acceptable consistency. The probabilistic risk of each fire safety factors was compared with the fire risk score in order to realize the risk status as shown in Table 7.

Table 7. Fire probabilistic risk score.

Fire probabilistic risk score	1≤R≤1.5	1.5<R≤2.5	2.5<R≤3.5	3.5<R≤4.5	4.5<R≤5
Risk ranking	Class 1	Class 2	Class 3	Class 4	Class 5
Risk status	worst	worse	good	better	best

Inherent fire hazard and evacuation factors were acceptable risk (good level of risk status) except the fire control factors were unacceptable risk (worst level of risk status). The three factors of fire hazard risk scores were 3.2830, 3.3178 and 1.4320 respectively as shown in Figure 7. Therefore, the fire control factors were mitigated by the practical recommendations. The suggestions for reducing

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the fire risk included check and test all fire emergency protection and response equipment according to monthly preventive maintenance plan, design and installation of portable fire extinguisher as NFPA10 [15] standard, make a suitable new floor plan including safety sign for the blind, and most importantly fire drills and basic firefighting must be carried out according to fire emergency plans in order for the blind to learn how to survive in the event of a fire.

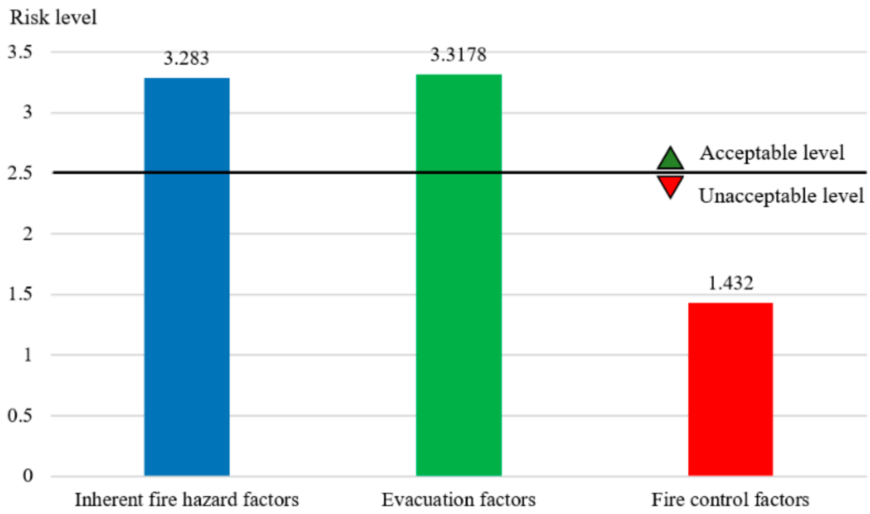

Figure 7. Fire hazard risk scores.

4. Discussion

Fires are the leading cause of death, serious injury and property damage. Moreover, it causes more damage among disabled especially the blinds who has a limited vision. Therefore, there is a need to assess the fire probabilistic risk in school for the blind building. Assessment the scores were based on brainstorming from fire experts. Expert Choice V.11 implemented the AHP for computing the relative weight each fire safety factors. Similarly, Ki-Chang Hyun et al. [16], Alberto Petruni et al. [17], Ali Kokangül, Ulviye Polat and Cansu Dağsuyu [18] and Maria Garbuzova-Schlifter and Reinhard Madlener [19] they were applied the AHP for calculating the relative weight for their decision goal. For this study applied an AHP to determine the relative weight of each fire safety factors from checklist and to determine the probabilistic risk in school for the blind building. This is the first application of AHP with fire checklist. No other research has been found to apply, but most of them would find applications of AHP to Fault Tree Analysis: FTA and Event Tree Analysis: ETA techniques. However, the reliability of the information has been conducted through extensive research and expert judgments to gain the relative weight of fire safety factors for assessing the fire probabilistic risk. As a result of the probability of occurrence is even more clearly defined without having to make sense of probabilistic risk assessment. In addition, Emre Akyuz, Ozcan Arslan, and Osman Turan [20] also applied the fuzzy logic to fault tree and event tree analysis of the risk for cargo liquefaction on board ship. This study is very similar to this one, but the technique used was simple to practice for the general public. Therefore, it is easy to assess the fire probabilistic risk. AHP technique is also suitable for the application. Finally, Meghann Valeo et al. [21], Abbas Bahrami et al. [22], and Mohammad Hossein Memary Nashalji, Abbas Bahrami, and Habibollah Rahimi [23] also found that checklist is a technique that can be applied for simple bridge security, occupational medicine status and performance of industrial occupational health experts respectively. This is similar to this study that has been applied checklist technique for assessing the fire probabilistic risk. However, there are differences between these studies: The implementation of AHP was used to make decisions for determining the relative weight for reducing bias assessments (subjective probability) including the scores of assessing the grade were obtained by brainstorming.

5. Conclusions

Assessing the fire risk of control is important in occupational health and safety, the results of the fire probabilistic risk assessment must be reliable. Consequently, this paper focused on conducting an AHP by Expert Choice V.11 for determining the relative weight from fire safety factors in order to estimate fire probabilistic risk in school for the blind building. As a result of the findings, school authorities (school director, deputy director of the school, staff, etc.) must set up a risk management plan or standard operating procedures. The procedures should include potential failures of measures to prevent fire hazards and actions to be conducted to prevent injury and death in order to efficiently address the risks that are likely to arise from routine operational procedures. Limitations of this study are based on the survey of only one school and brainstorming of fire expert for determining the grade assessment. Therefore, it may not represent the actual of the situation because of limited time and resources available. However, it represents the generalize facts.

In conclusion, this paper will help researchers and school administrator for decreasing potential risks during study in the school. The further studies may be extended with quantitative risk assessment and Fuzzy Analytic Hierarchy Process (FAHP) approach to manipulate uncertainty in a better way.

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Informed Consent Statement: Not applicable.

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