ASSESSING FIRE RISK MANAGEMENT OF HIGH-RISE RESIDENTIAL BUILDING IN THE CONTEXT OF MID-SIZED CITY, KHULNA

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ABSTRACT

The present urbanization in Bangladesh is leading to an increase in the construction of multistory buildings of which 30% are residential . Unfortunately, over 67% of these high-rise structures are deemed moderately risky in terms of fire safety, posing a significant challenge to fire safety in urban areas. It led to more than 500 people being harmed in 24102 fire cases in the past year. To this end, the article is considered to evaluate the sensitivity of fire hazards in the expanding high-rise residences in Khulna, Bangladesh, enabling risk identification, risk prediction, and possibly implementing effective risk reduction. This descriptive study is designed to explore the feasibility of combining quantitative and qualitative research techniques, which frame these three integrated models. (1) The dual-phase model; physical survey in the city to gather data on the architectural properties and fire installation of each surveyed building. (2) The event tree model; establishes a probability risk assessment criterion by using a probabilistic technique. (3) Subjective evolution; determines the chance of a fire developing and classifying the effects, to assess the degree of injury to the occupant, executing a descriptive risk scenarios synthesis and influences the necessary actions to lessen the risk rate. In order to better understand the likelihood of different events occurring, we have identified four layers of probability. Among these layers the suppression phase (layer 2) is particularly strong, controlling 80% of all potential ignition and providing significant protection against most events. However, there is still a chance (0.02 probability) of extreme scenarios that could result in significant loss of life, particularly in residential areas. This research presents a thorough analytical approach that combines various methods to assess building fire safety. Examining the categorization of risks and their consequences can aid authorities in taking appropriate actions to enhance fire safety and firefighting capabilities.

Keywords: *Fire-risk, High-rise residence, Mid-sized city*

1. INTRODUCTION

Fire, despite being a vital part of human life, has the potential to cause massive devastation while going out of control, which makes it one of the most dreaded threats in contemporary society causing great economic loss and killing people within a very short time. Sadly, the number of fire incidents has been rapidly increasing, especially in urban areas where 39.71% of the total population resides as of 2022. Since 1997, the number of fires in Bangladesh has more than tripled, with an average of 66 fires per day in 2022. Table 1 shows the fire incident data with the total annual property loss.

Table 1: Fire Incident by Years

Year	Incidents	In Residence	Percentage (%)	Total Loss(tk)
2019	24074	8466	35.16	3300 M
2020	21073	6150	23.18	2466 M
2021	21601	5818	26.9	2183 M
2022	24102	6558	27.2	3425 M

Fire accidents increased by 11.57% from the previous year. In 2021, there were a total of 21601 fire accidents, resulting in 2183197403 tk worth of property loss, which rose to 3425851389 tk last year (FSCD, 2022). Table 1 shows the fire incident data with the total annual property loss. According to an article from the Daily Star on October 7, 2023, there were 1577 incidents of fire in September, averaging 52 per day. Out of those, 132 cases happened in Khulna, the third-largest city in the country. The city's lack of proper industrial and economic development, combined with the prevalence of unplanned building structures, may have contributed to the high number of incidents. Recent analysis indicates that fire incidents occur most frequently in residential areas, particularly in high-rise buildings, accounting for 27.2% of all incidents in the past year. This puts the residential apartments in Khulna at a higher risk for fire hazards, as nearly 90% of them were constructed in violation of the Bangladesh National Building Code (BNBC, 2020). For safety purposes, the BNBC code requires residential buildings to have a stair that is at least 1.5m wide and a fire exit door of combustible material. These must be accessible to all residents for safe evacuation. A deficient water supply often worsens fire accidents, so every building must have a rooftop water store dedicated to fire safety. Additionally, firefighting equipment such as CO_2 extinguishers, Water mist suppression, Foam suppression, sand buckets, etc. must be available inside the building and easily attainable. Since current buildings do not meet the standard set by the authority, it is necessary to conduct a risk index assessment to determine the level of fire hazard risk for both the building and its occupants. The primary goals of the research presented in this paper are to analyze the available data through quantitative statistical data comparison of physical building properties such as building position, occupancy classification, construction group, openings, fire resistance barriers, lift shaft, and fixed or portable firefighting equipment to set up the risk scenario clusters using probability method and qualitative evaluation of the risk picture to identify the hazardous practices in Khulna to mitigate the corresponding risk. Last but not least, the results and a few suggestions have been included in the risk notes for the existing structures, which can make the residential area safer and assist the authorities in taking the necessary action.

2. LITERATURE REVIEW

The method of assessment of fire risks based on standard rules, and requirements, with a view to enhancing fire safety, is essentially an experimental decision-making process. Knowledge of the physical features of buildings, equipment, and building construction standards is needed in order to address this specific problem. A review of the Bangladesh National Building Code (BNBC), and current fire safety requirements in Bangladesh is set out in this section. In addition, a discussion is provided of the presently existing practices aimed at determining building fire protection systems, which is essential for supporting the methodology to assess the existing risk management in this article.

2.1 Bangladesh National Building Code, BNBC

The (BNBC), the book of standard requirements to determine the architectural features, design of physical components, and other apparatus, is observed by the authority of the Housing and Building Research Institute (HBRI). Initially established in 1993 for industrial frameworks only, it has undergone various changes over time, which now include all safety aspects including fire for different types of buildings. BNBC 2015 is organized into different sections. Part 4 covers fire protection requirements for the architectural components and safety appliances according to each building type.

2.1.1 General Requirements & Physical Features

The rules and requirements for construction are divided into classes based on their intended occupancy. Residential buildings belong to the Class-A type, while flats and apartments are categorized under A-2. The height and area allowed for construction depending on the type of residential building. For plots measuring between 134 sqm and 670 sqm, with a 6m road access, the floor area ratio (FAR) should be maintained between 3.15 and 4.5. To ensure easy access for fire apparatus, roads leading to the building should have an unobstructed width of 4.5m and a minimum vertical clearance of 5m. The setback of the building determines its height limit, which varies from a setback of 5m to 10m for a building that is 11.2m to 30m tall. It's crucial to take into account several structural barriers that can resist fire for 3 to 5 hours, especially when it comes to RC slabs. For 250mm clay brisk it can be around 3 hours.

Table 2: Fire Resistance Rating

Structural Element	Fire Resistance Rate
75mm thick wall of clay brick	0.75 Hours
125mm thick wall of clay brick	1.5 Hours
250mm thick wall of clay brick	3 Hours

It is important to ensure fire-separating walls do not exceed 11.2 square meters in area. The size of all openings in these walls should be within 25% of the barrier's length. If you use skylight glass, it must not exceed 5 square meters in area and 6 mm in depth. For not having any mechanical ventilating components or the Heating, Ventilation, and Air Conditioning (HVAC) system which means if the building is using natural ventilation, an exhaust fan is a must to save everyone from gas-leaking-related fire disasters.

2.1.2 Means of Escape

The purpose of this section is to highlight the escape safety requirements for an emergency evacuation, which can be done by ensuring three events such as exit access, exit features, and exit discharges. The corridor-like features are required to be at least 1.1 meters wide and 2.4 meters high. It must be clear and easily accessible to the exit door in walking distance of 23 meters, which must open directly to the outside. Dead-end corridors cannot exceed 10 meters. Exit pathways must have a fire-resisting rating of at least one hour. Sliding doors are not allowed as exits; the width of the exit must be at least 1 meter, and the height should be no less than 2 meters. For flats or apartments with an occupancy of 500 or less, two exits are required, with a stair width of at least 1 meter and handrails on both sides. All these standards are necessary to ensure safe evacuation during an emergency.

2.1.3 Firefighting Apparatus

This chapter discusses the firefighting equipment and design elements that are necessary for residential buildings. Fire accidents are often worsened by inadequate water supply. To prevent this, all buildings must have a rooftop tank for fire protection. Firefighting equipment such as water mist suppression, CO_2 extinguishers, foam suppression, and sand buckets should be easily accessible and placed inside the building. For A2 occupancy types, fire detection and fixed firefighting are not necessary. It's important to maintain manual firefighting appliances and extinguishers over time, for preventing fire at the moment.

2.2 Present Practices & Contravention

The current practices and situations do not fully comply with the regulations. Building standards and rules are not being effectively enforced and monitored, which leads to illegal components and features in most multi-story buildings. For instance, many buildings exceed the permissible height, as seen in the case of Rana Plaza and other buildings. Additionally, most buildings lack proper emergency or fire exits, with the same stairwell serving both purposes. The design is also not proportionate to the occupancy load, leading to further safety hazards. One of the most common practices that threaten the safety of occupants in buildings is the disregard for setback and access road regulations. In case of emergencies, firefighters are unable to access the building due to this violation. This situation is exacerbated by inadequate monitoring of implementation, which results in non-compliance with the plan approved by the authority. These factors make the building spaces more vulnerable to occupants.

It is crucial to prioritize the improvement of fire safety in these buildings, as they are said to account for 90% of rule violations. Traditional approaches and data analysis may not be enough to identify the hazardous complexity of the existing phenomena. So, an integrating methodology is suggested to remark the fire scenarios depending on the existing situation of a building and asses the risk possibility, which is described in the upcoming section of the article.

3. METHODOLOGY

Preventing fire accidents combines reducing the foremost reasons that happen if safety standards are not followed by a building, as well as the events where the fire protection system fails to work in an emergency. The study is intended to assess for both of the reasons. The first portion is to analyze the physical components of a building and the fire equipment based on the requirements set by the Bangladesh National Building Code (BNBC) and the Bangladesh Fire Service and Civil Defense (BFSCD). Later on, the study transforms the analysis into fire events illustrations using a probabilistic perspective, which may quantify the quality of the possibility of fire protection in all possible emergencies.

3.1 The Dual-Phase Model

The first phase is to evaluate the survey data and the present condition of these selected buildings. We conducted an analytical comparison of their current state and highlighted the issues that need attention. Khulna is the third-largest city in the country, with 49 high-rise structures (Molla, M. Al 2019). Unfortunately, most of the residential buildings in the city do not comply with the standards and regulations set by the authorities. We analyzed case studies and fire incidents that occurred in the city to determine the building areas to survey, which is presented in the first phase. Later, in the second phase, we performed quality indexing between all cases and the risk value by reviewing the literature according to the standards.

3.1.1 Physical Survey and Inspection

The purpose of the survey was to assess the current state and structural characteristics of a specific area. The study areas were specified by analyzing the data (from the KCC record) of the growing construction of residential highrises in the city and consulting with the Khulna City Corporation (KCC) officials, some hotspot areas or developing zones (for instance Nirala Abashik, Mujgunni Abashik, Tutpara) were identified based on their characteristics and diversity. Later on, after perusing over 30% of data on residential structures in those areas, the following 5 residential buildings were selected as specified case studies for physical examination and a questionnaire to evaluate the impact of fire hazards on the occupants. All survey parameters and factors were selected according to the BNBC 2015 code.

3.1.1.1 Selection of study area

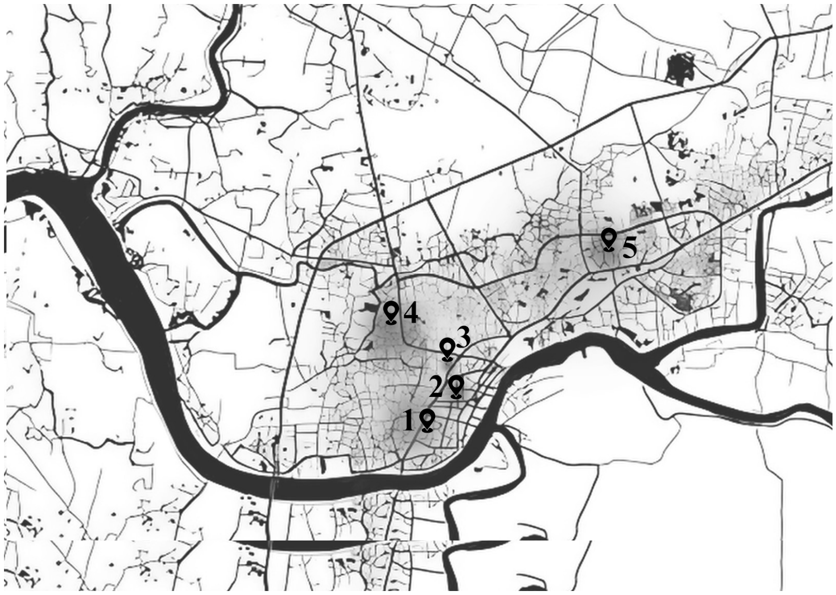

Figure 1: Site Position, Khulna City

Figure 1: illustrates five residential projects in Khulna City, including recent constructions and prominent residential zones as previously mentioned of the developing zones like Nirala Abashik, Mujgunni Abashik, and Tutpara.

The study criteria are chosen by observing the literature review to determine issues related to safety and risk factors such as building location, construction type, occupancy class, setback, road size, plot type, height, floor area, usability, fire stair data, and other residential firefighting considerations. The selected buildings to study are,

1. Building X_1 – 79/2 khan jahan ali road, Khulna
2. Building X_2- shamsur rahman road, Khulna
3. Building X_3- 50/1 farazipara main road, Khulna
4. Building X_4- dighi paar, nirala, Khulna
5. Building X_5- 26, boyar, gowalkhali road, khulna

3.1.1.2 The Survey Data

In this study, an attempt is made to collect the fire potential data of buildings in Khulna, based on both physical features and firefighting components. The physical features are classified into six categories, namely occupancy load, building arrangement, escape data, floor area data, and residential considerations. These findings are presented in Table 3.

Table 3: Surveyed Information

Specification	Building X_1	Building X_2	Building X_3	Building X_4	Building X_5
Construction Year	2021	2020	2022	2023	2022
Mixed or Not	Separated	Separated	Separated	Separated	Separated
Avg. People/Floor	16	15	3	10	6
Front Road (m)	18	10	7	10	7
Nos. of road	1	2	1	2	1
Setback Front(m)	1.5	1.5	0.6	1.5	2.0
Setback Right, Left	1.0	1.5	0.6	1.5	2.0
Setback Rear	1.0	1.0	0.6	1.0	2.0
No. of Floors	8	9	7	10	11

Avg. Floor Height	1.2	1.0	1.0	1.0	1.1
Total Floor Height	9.6	9.0	7.0	10	10
Area (sqm)	555	355	335	366	783
No. of Fire Exit	1	1	0	1	1
Dimension(m)	4.5*1.5	4.0*1.1	-	4.0*1. 2	4.5*1.5
Stair Type	Closed- Dog Legged	Open- Dog Legged	Open- Dog Legged	Open- Dog Legged	Closed- Dog Legged
Regular Use	No	No	Yes	No	No
Access Corridor	1.0	1. 2	1.0	1. 2	1.5
Barrier Fire Resisting Rate(hr)	1.5	1.5	1.5	1.5	1.5
Nos. of Water Reservoir	1	1	1	1	1
Reservoir Capacity (L)	20000	15000	15000	15000	30000
Reservoir Position	Underground	Underground	Underground	Underground	Underground
Fire Station <5km	-	-	-	-	2
Water Body<500m	-	-	-	1	-
Electrical Substation	1	1	-	1	1
Generator					
Water pump/Diesel	1	1	-	1	1
Pump	-	-	1	1	2
Fire Alarm					
Intercom per floor	-	-	-	-	-
Fire Safety Signage	1	1	0	1	1
Exhaust Fan/ Unit	-	-	-	-	-
Fire Extinguisher/					
Floor	1	1	0	1	1
Fire Hydrant Box (FHB)	1	1	0	1	1
	1	-	0.5	-	1

3.1.2 Comparative Data Analysis

After surveying the design components, a preliminary data analysis is conducted to identify potential hazards. After conducting an analysis, the condition is compared against the requirements outlined in the literature review. The findings suggest four distinct prevention layers that can be utilized to combat fire incidents with three different conditions, as shown in Table 4.

Table 4: Analysis Remarks

Condition	**Remarks**
Good	8-9
Intermediate	5-7
Poor	3-4

Conducting a fire risk assessment is crucial in preventing and controlling fire incidents, as it considers various data. Adopting a semi-quantitative risk technique, like condition remarks, is effective in this scenario as it is easy to use and offers a quick and simple evaluation of relative fire hazards in buildings by rating various factors.

3.2 The Event Tree Model

In order to assess the effectiveness of the fire protection system, an event tree model is generated. This model groups together different fire possibilities and compares them to identify the most likely scenarios. First, a generalized functional model is used to project the total ignition frequency. Then, a probability scenario cluster is drawn to understand the risk involved. This helps us to manage countless fire events better by reducing them to a more manageable number. The event diagram displays all possible positive (1) or negative (0) reciprocations in the protection process, resulting in various branches and outcomes (Figure 1).

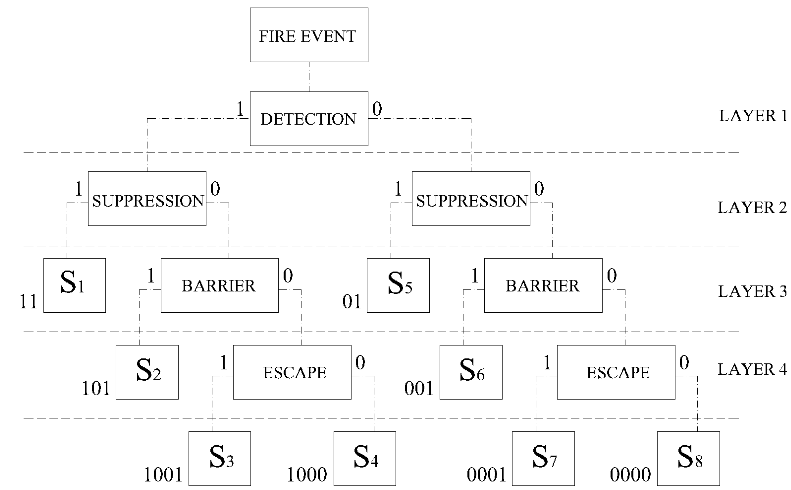

Figure 2: Event Tree Diagram

3.2.1 Ignition Frequency

Predicting the frequency of fire ignition is crucial, and it requires careful quantification. To determine the annual ignition frequency, it needs to analyze statistical fire data for a year and the total floor area, taking into account the occupancy category as a variable. However, floor statistics can be challenging to use in practical scenarios. A more efficient approach is to use the generalized Barrois model as equation (1), which was originally proposed by Charles Barrios in 1835. This model involves two power-law functions in a specific category and provides a more straightforward and practical solution. In this article, the average floor area of the selected buildings is used to assess the risk for those specific buildings. The coefficients for the generalized barrios model are in Table 5.

$$P_1 (A)= C_1A^r + C_2A^s \tag{1}$$

Here, for a certain floor area A, P1 (A) represents the frequency of total ignition of a specific building within a year, and C_1, C_2, r, and s are coefficients.

Table 5: Parameters of the generalized Barrios model

Building Category	C_1	$C_2 * 10^{-6}$	r	s
Residential Building	0.010	5	-1.83	-0.05
Commercial Building	7*10^-5	6	-0.65	-0.05
Office Building	0.056	3	-2.00	-0.05
Institutional Building	2*10^-4	5	-0.61	-0.05
Educational Building	0.03	3	--1.26	-0.05
Industrial Building	3*10^-4	5	-0.61	-0.05
Other Buildings	1.18	100	-1.87	-0.20

In this article, the Barrios model is used to estimate the probable ignition frequency in one year, in which the coefficient changes according to the building category. It should be noted that the generalized model does not provide any numerical estimation of the risk or quality of the fire components. Instead, it is aimed at depicting a cluster of risk scenarios based on a probabilistic method and analyzing how much of the total fire event remains risky as per the present condition of the building. The Barrios model coefficients are considered for floor areas of 100 sqm to 20000 sqm.

3.2.2 Probability of Fire Scenarios

To predict the likelihood of fire events and the actions required in response, an event tree is abstracted based on the ignition frequency. Different fire situations are illustrated, depending on whether the protective components respond positively or negatively. A fire scenario consists of each potential response to an occurrence and is grouped with other possible responses. The probability is made in four layers naming detection (Det.), suppression (Sup.), the act of barrier (Bar.), and the chance of escape (Esc.), where the first one is the recognition phase and the rest three are reduction phases. Here, 0 represents the negative response and 1 is regarded as the affirmative representation of the layers. Following the different branches of the event tree diagram (fig. 2) different decisions are made according to their respective feedback of 0 or 1. The earlier the layer response in 1, the safer the scene is. The binary decision diagram presents the clustered settlement as well as the situation reciprocation, as in Table 6.

Table 6: Binary Decision Table

Total Ignition	Det. (0.47)	Sup. (0.80)	Bar. (0.70)	Esc. (0.66)	Fire Scenario	Ignition Value
	1	1	-	-	S_1-11	1.28E-6
	1	0	1	-	S_2-101	2.24E-7
	1	0	0	1	S_3-1001	6.30E-8
3.4E-6	1	0	0	0	S_4-1000	3.30E-8
	0	1	-	-	S_5-01	1.44E-6
	0	0	1	-	S_6-001	2.52E-7
	0	0	0	1	S_7-0001	7.13E-8
	0	0	0	0	S_8-0000	3.67E-8

The ignition value for each scenario is estimated from the probable calculation of the layer possibilities as presented below in Table 7 to Table 10. The scenario codes are presented in the response of different layers, as presented in Fig 3.

3.2.3 Layer Possibilities

Based on the survey's data analysis, opportunities for different layers of risk prevention can be identified depending on the condition of each component. According to Table 10, the component's condition is determined and remarks have been made accordingly. The scores for each building are different, depending on the floor number, which determines the impact of each individual residence on the article.

Early detection of a fire is crucial for safety. Detectors have a high success rate of 0.70 to 0.90 in detecting fires. However, in the absence of either manual or automatic detectors, the chances of people identifying a fire are significantly lower. Table 7 presents the average possibility of detecting a fire from the conducted data.

Table 7: Detection Possibility

Building	Detection Remarks	Possible Score (all floors)	Avg. Possibility
Building X_1	5	4.0	
Building X_2	5	4.5	

Building X_3	3	2.1	0.47
Building X_4	5	5.0	
Building X_5	5	5.5	

It's important to detect a fire within 3-5 minutes before the heat release rate increases to increase the chances of successfully extinguishing it. For households, having a fire extinguisher, fire hydrant box, and reservoir, as shown in Table 8, is considered good for suppression. The conditions are remarked depending on their present condition and requirement.

Table 8: Suppression Possibility

Building	**Suppression Remarks**	**Possible Score (all floors)**	**Avg. Possibility**
Building X_1	9	7.2	
Building X_2	8	7.2	
Building X_3	5	3.5	0.80
Building X_4	8	8.0	
Building X_5	9	9.9	

According to the BNBC 2015 code, solid clay brick with a thickness of 125mm can be considered a barrier for fire incidents lasting up to 1.5 hours. On the other hand, RCC barriers may offer better protection for up to 3 hours. For residential structures, 125mm thick walls with RCC slab barriers can be considered intermediate as presented in Table 9.

Table 9: Barrier Possibility

Building	**Barrier Remarks**	**Possible Score (all floors)**	**Avg. Possibility**
Building X_1	7	5.6	
Building X_2	7	6.3	
Building X_3	7	4.9	0.70
Building X_4	7	7	
Building X_5	7	7.7	

Escape is an essential component of fire safety. Properly designed stairs and access dimensions can help ensure a safe exit in the event of a fire. However, intermediate and lower-grade fire exits do not always meet safety standards, as noted in Table 10.

Table 10: Escape Possibility

Building	**Escape Remarks**	**Possible Score (all floors)**	**Avg. Possibility**
Building X_1	9	7.2	
Building X_2	5	4.5	
Building X_3	3	2.1	0.66
Building X_4	6	6	
Building X_5	9	9.9	

Figure 3 illustrates the mitigation of fire risk in different layers and scenes. Layer 2 offers the most significant risk reduction, with a value of 0.42 in scene 5. By comparing the total ignition and layered scenes, the image of fire prevention as a whole can be dramatized. The tree diagram provides details on all layers for each scene prediction.

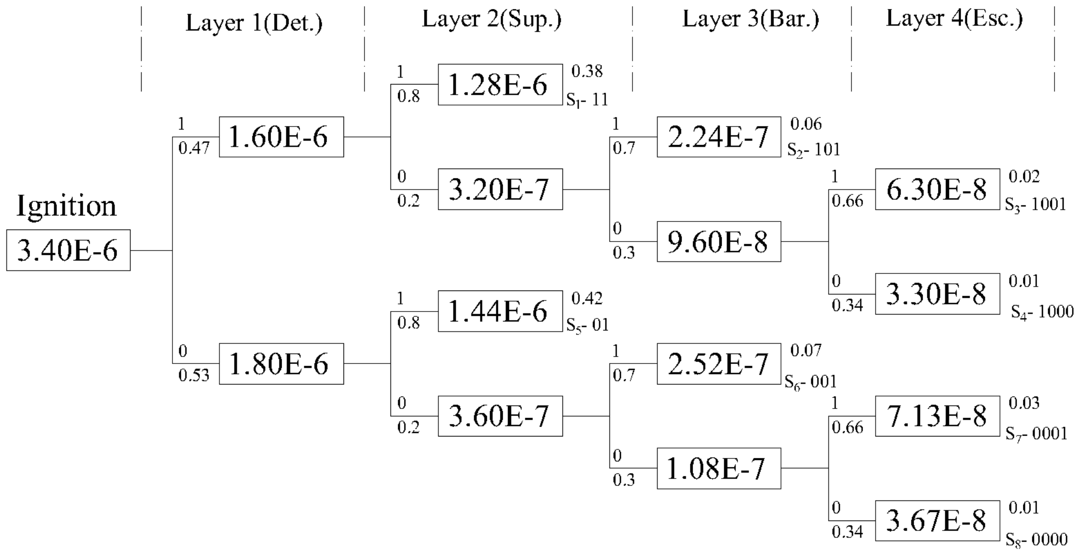

Figure 3: Event Tree Analysis

3.3 Subjective Evolution

In this section of the article, we assess the fire events in terms of risk by evaluating them based on the predicted risk, as indicated in Table 11. The events that are mitigated in layer 2 are considered to be the least risky with a possibility of 0.8. Layer 3 is slightly riskier, as it does not include any suppression action. In layer 4, scene 4 and scene 8 are the most extremely risky, as they indicate unsuccessful escape from fire events.

Table 11: Risk Prediction

Risk Level	Layer	Scene	Possibility	Consequences
Low	2	S1, S5	0.8	Slight Harm
Low Medium	3	S2, S6	0.13	Acute Harm
Medium High	4	S3, S7	0.05	Moderate Harm
High	4	S4, S8	0.02	Extreme Harm

Low-risk events have a maximum possibility of causing slight harm, which is estimated to be 0.8. Slight harm is not expected to result in serious injury or death to any occupants. However, in high-risk level events, the possibility of severe harm or death is significantly greater. In such cases, occupants may find it difficult to escape the scene and the potential for massive fatalities is much higher.

To address low-risk possibilities, regular monitoring of the structure is sufficient and no additional action is required. To prevent medium-risk situations, it is necessary to regulate and develop escape routes in accordance with building codes. In the event of high-risk scenarios, the building should not be occupied until the risk is reduced to a lower medium level or lower.

4. CONCLUSION

Fires in high-rise buildings in Bangladesh have caused a concerning increase in casualties. The city of Khulna is particularly worried about the safety of tall structures since their number is rising in urban areas. Evacuating people from a high-rise building during a fire is much more challenging than preventing the fire from spreading. It is essential to use both quantitative data and qualitative analysis to accurately assess all potential outcomes. The article combines the physical data into probable implementation of those components. After analyzing the event scene cluster, it has been confirmed that the majority of fires can be suppressed by layer 2. The probability of an event causing harm up to layer 4 is much lower, at around 2%, compared to other layers. This is concerning because a risk of 0.02 is unacceptable as it can lead to the loss of the entire building, causing significant damage to property and human life. Occupants cannot tolerate this level of risk, especially when it can result in mass casualties. So, proper action should be taken in order to prevent these fire scenarios, even if it's the lowest possible scene. However, even with the study's comprehensive evaluation of all potential risks, there are still a few limitations that need to be considered. It does not include the consideration of the logical development of fire events and the quantification parameters of fire risk are based on statistical data. Collecting and processing data using evaluation methods is a time-consuming process. Additionally, fire safety and hazard events are influenced by various factors and variations in design components and occupants. Therefore, any future implementation of the process should consider these limitations and adjust the statistical data accordingly.

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