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Analysis of University Cafeteria Safety Based on Pathfinder Simulation

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Abstract

Recent years have seen a notable increase in fire incidents in university cafeterias, yet the social attention to these occurrences remains limited. Despite quick responses to these incidents preventing loss of life, the need for large-scale evacuation in such high foot traffic areas can cause significant disruptions, economic losses, and panic among students. The potential for stampedes and unpredictable damage during inadequate evacuations underscores the importance of fire safety and evacuation research in these settings. Previous studies have explored evacuation models in various university environments, emphasizing the influence of environmental conditions, personal characteristics, and behavioral patterns on evacuation efficiency. However, research specifically focusing on university cafeterias is scarce. This paper addresses this gap by employing Pathfinder software to analyze fire spread and evacuation safety in a university cafeteria. Pathfinder, an advanced emergency evacuation assessment system, offers realistic 3D simulations, crucial for intuitive and scientific evacuation analysis. The studied cafeteria, encompassing three floors and various functional areas, often exceeds a capacity of 1500 people, primarily students, during peak times. The study includes constructing a model of the cafeteria in Pathfinder and analyzing evacuation scenarios under different fire outbreak conditions on each floor. The paper sets standard safe evacuation criteria (ASET > RSET) and formulates three distinct evacuation scenarios, considering different fire outbreak locations and initial evacuation times on each floor. The simulation results reveal the impact of the fire's location and the evacuation preparation time on the overall evacuation process, highlighting that fires on higher floors or longer evacuation preparation times tend to reduce overall evacuation time.In conclusion, the study emphasizes a multifaceted approach to improve evacuation safety and efficiency in educational settings. Recommendations include expanding staircase widths, optimizing evacuation routes, conducting regular drills, strengthening command during evacuations, and upgrading emergency facilities. The use of information and communication technology for managing emergencies is also suggested. These measures collectively form a

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comprehensive framework for ensuring safety in educational institutions during fire emergencies.

Key Words: *University Cafeteria, Pathfinder Simulation, Emergency Management, Safety Recommendations.*

1. INTRODUCTION

In recent years, there have been numerous fire incidents in university cafeterias, but social attention to this issue remains insufficient. Most fire incidents are promptly addressed, preventing loss of life and hence not receiving significant social attention. However, university cafeterias, being areas with high foot traffic, require large-scale evacuation procedures during fire incidents, potentially causing severe disruptions to the daily routines of students and staff, as well as economic losses and panic among students. Inadequate and improper evacuation can lead to accidents such as stampedes, making the potential damage unpredictable. Therefore, research on fire safety and evacuation in university cafeterias is deemed crucial.

Xu Yanqiu (2012) and colleagues used FDS software to study evacuation models in school classrooms and analyzed the impact of various personnel characteristics on evacuation efficiency [1].

Le Zeng (2009) and others employed FDS and Pathfinder for fire and evacuation numerical modeling in student dormitories, analyzing smoke movement, temperature distribution, and visibility changes during fires, providing guidelines helpful for on-site firefighting operations [2].

Helbin (1995) experimentally studied and numerically simulated the evacuation process in university dormitories, discovering the impact of pedestrian evacuation dynamics [3].

Isobe (2004) found through walking experiments and simulations that evacuation behavior differs significantly in familiar and unfamiliar environments in university technical buildings [4]. These studies emphasize the importance of effective personnel evacuation in fire situations, where different environmental conditions, personnel characteristics, and behavioral patterns greatly influence evacuation efficiency. These researches enhance understanding and optimization of evacuation strategies in fire situations, thereby improving safety and efficiency.

University cafeterias are key gathering places for students. However, fire incidents can lead to panic among students, significant economic losses, and casualties. Therefore, numerical simulation studies on the safety of evacuation during fires in university cafeterias are essential. While research on fire safety in schools mainly focuses on areas like dormitories, libraries, and classrooms, studies on cafeteria evacuation are rarely mentioned.

Evacuation in building fires is influenced by various factors due to the complex nature of fire causes and processes. Traditional experimental methods are time-consuming and costly, often yielding limited results. However, numerical simulation research using Pathfinder software can effectively reduce time and costs while providing a more intuitive simulation of the evacuation process in fire scenarios. Therefore, this paper employs Pathfinder software to analyze the spread of fire and safety of evacuation in a specific university cafeteria building, aiming to provide data for fire safety management and student evacuation in universities.

2. MAIN BODY

Pathfinder is an intuitive and straightforward personnel emergency evacuation assessment system developed by Thunderhead Engineering, based in the United States. The software offers an advanced

visualization user interface, complete with 3D animation effects. Its built-in character library includes various setting options, providing more realism and superior graphical effects compared to similar types of simulators. Moreover, it features a complete 3D triangular grid design function [5]. These realistic representations of people provide users with a lifelike experience. Pathfinder supports standard graphics cards, allowing for smooth real-time animation simulations for thousands of individuals, thereby providing more scientific data in modeling and simulation analysis.

2.1 Building Overview

This cafeteria measures 60 meters in length and 20 meters in width, comprising three floors. Inside the building, there are spaces such as an electrical room, food storage, freezer storage, vegetable storage, stir-fry cooking area, and a food receiving area. There is a large dining space in the middle, and inside the building, there are two indoor staircases and three safety exits on the first floor. The cafeteria's maximum capacity exceeds 1500 people at peak demand times, most of whom are students, with some faculty and kitchen staff. Field surveys revealed that due to different food preferences, more people dine on the first and second floors, while the third floor tends to have fewer people. A model of this cafeteria was constructed using Pathfinder software, as shown in Figure 1.

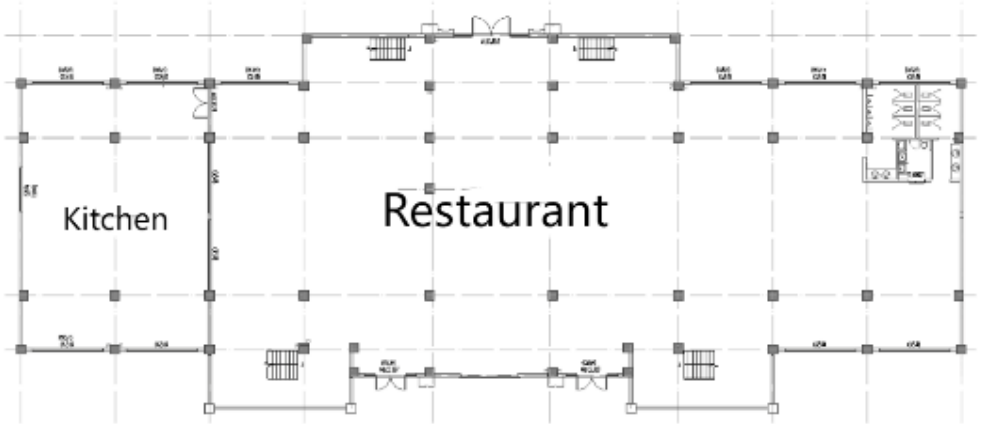

Figure 1. Architectural Floor Plan

2.2 Construction and Simulation Analysis of the Evacuation Model Based on Pathfinder

Pathfinder supports two types of movement simulation models. In the Steering model, doors do not restrict the movement of individuals, and a reasonable distance is maintained between individuals. In the Social Force Model (SFM), people do not avoid each other and may push through while doors restrict movement. The movement of individuals is controlled by the population density within the space [7]. As can be inferred from the analysis of the cafeteria's structure and personnel flow, the cafeteria occupies a large area, and the personnel flow is moderate during peak hours. During emergency evacuation, the doors are less of an influencing factor and the likelihood of congestion is low, thus, a specific SFM model could be applied. However, considering the decisive aspects of this design, the Steering model might better model the actual scenario in personnel evacuation.

2.3 Estimation of Occupancy and Building Modeling

Initially, a single-line plan model in Pathfinder's 2D view is created based on the architectural design drawings of a specific university cafeteria. This is represented in Figure 2. Building on the previous step, all evacuation floors are combined to construct the complete frame of the 3D structure for the simulation model. This is illustrated in Figure 3.

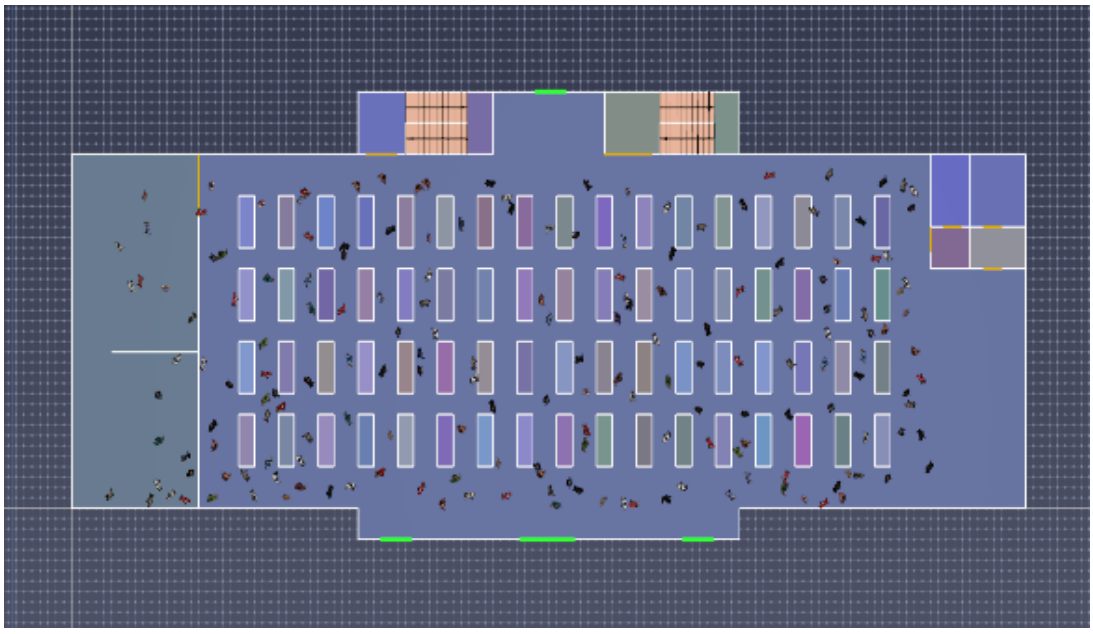

Figure 2. 3D Floor Plan

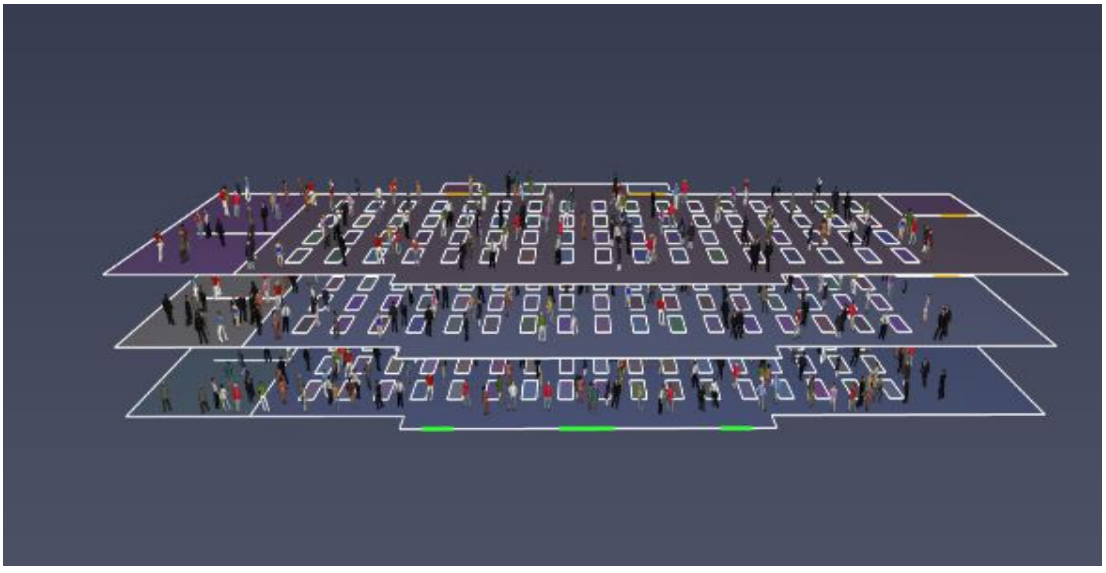

Figure 3. 3D Modeling View

Safe evacuation of personnel from a building should be completed within a set time to prevent collective

trampling accidents. The standard for safe evacuation is as follows:

ASET > RSET. (1)

Here, ASET (Available Safe Egress Time) refers to the time available for people to safely leave the building or hazardous area in the event of a fire or other emergency.

RSET (Required Safe Egress Time) is the actual time needed for everyone to evacuate safely from a specific building or structure during a fire or other emergency.

The essential safe evacuation time, RSET, is the time from the start of a fire until all individuals in the building have completely evacuated. It can be expressed with the formula:

RSET = ta + tp + tm (2)

Where:

- ta (Alarm Time): The time it takes for the fire alarm to sound and for people to recognize and begin responding to the fire.

- tp (Pre-movement Time): The time before people actually start moving.

- tm (Movement Time): The time it takes for people to follow the evacuation routes and move to a safe area or outside the building.

In this context, the alarm time is influenced by the sensitivity of the alarm system and the real-time situation on site, and in this study, it is set to 30 seconds. tp is affected by individual subjective consciousness and is set at 50 seconds in this study, assuming most cafeteria patrons are familiar with the cafeteria layout and there are few obstacles. The evacuation time is obtained through evacuation simulations using Pathfinder.

Evacuation preparation time refers to the duration from the onset of the fire until the critical state where human safety is at risk. This time is influenced by the building's fire resistance rating and the effectiveness of fire extinguishing devices. Referring to "Architectural Fire Protection Design" and "Safety Evacuation Passage Requirements and Facilities," large and complex public buildings should have a fire resistance rating of Grade 1 or 2, and the evacuation time for such grades should not exceed 5 minutes. Therefore, in this paper, the evacuation preparation time is set to within 5 minutes, specifically at 3 minutes【6】.

2.4 Personnel Settings

The behavioral characteristics of personnel are crucial factors influencing evacuation in the event of a fire incident in the Pathfinder software, directly determining evacuation time and efficiency. Therefore, the selection of parameters based on the behavioral characteristics of personnel is key to the accuracy and realism of the evacuation simulation results.

(1) The total number of evacuees is 560, randomly assigned. The characters are modeled with an average shoulder width of 50.0 cm and height of 1.7 m, with the rest being standard settings.

(2) The composition of the personnel is relatively simple. Individual differences are ignored, and it is assumed that everyone has normal physical abilities. The personnel ratio is 50% men and 50% women.

(3) The average walking speed of the personnel is set at 1.2 m/s, and the average evacuation speed during an emergency is set at 2 m/s. In addition, response acceleration and duration times are set, and individuals within the area are randomly placed. The individual behavior patterns in Steering mode are shown in Table 1.

Table 1. Parameter Settings

Item	Description
Number of Evacuees	560
Allocation of Personnel	Randomly assigned
Shoulder Width of Characters	50.0 cm
Average Height	1.7 m
Personnel Composition - Male Ratio	50%
Personnel Composition - Female Ratio	50%
Average Walking Speed	1.2 m/s
Average Evacuation Speed	2 m/s
Response Acceleration and Duration Settings	Set
Distribution of Individuals in Areas	Random distribution
Behavioral Model	Steering Mode

3. SCENARIOS

Setting the evacuation preparation time to 2-3 minutes is particularly practical and achievable for large bui ldings like university cafeterias. This time range takes into account the entire process from the issuance of th e alarm to the start of evacuation, including risk perception, alarm response, evacuation organization, and oth er stages. Therefore, in the event of a fire, the initial inability to detect and evacuate immediately from the so urce of the fire is considered. Hence, three different scenarios are established.

Table 2. Scenarios

Scenario	Fire Outbreak Floor	Evacuation Start Time on 1st Floor	Evacuation Start Time on 2nd Floor	Evacuation Start Time on 3rd Floor
Scenario 1	**1st Floor**	**Immediately**	**After 180 seconds**	**After 180 seconds**
Scenario 2	**2nd Floor**	**After 120 seconds**	**Immediately**	**After 180 seconds**
Scenario 3	**3nd Floor**	**After 180 seconds**	**After 120 seconds**	**Immediately**

4. SIMULATION RESULTS

Figure 4 illustrates the first evacuation route in Scenario 1. As shown in the figure, the evacuation routes of individuals are influenced by the arrangement of tables and chairs in the cafeteria. An orderly arrangement of tables and chairs, along with wider spaces between them, aids in the evacuation process. Additionally, in emergencies, individuals tend to choose evacuation routes that offer the shortest straight-line distance.

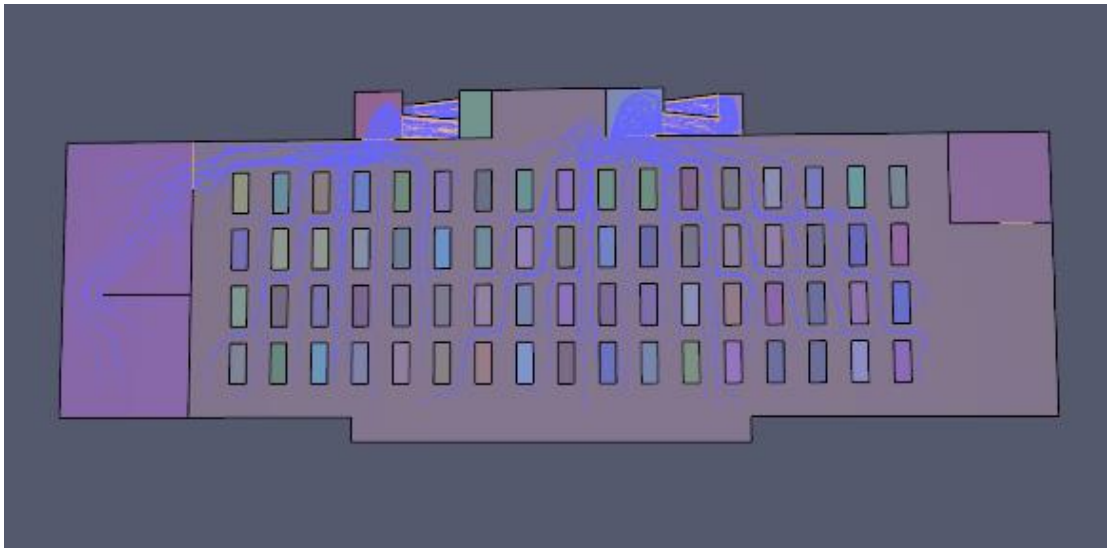

Figure 4. Evacuation Route in Scenario 1

Figure 5 presents the flow curves over time for each floor in Scenario 1. The total evacuation time for all individuals in Scenario 1 is 177 seconds, meeting the evacuation criteria for personnel. The flow in the higher floor staircases is initially low for all, and the flow curve of the staircase evacuation shows an initial decrease followed by an increase. The primary reason is that the individuals on the 3rd floor do not evacuate first at the beginning of the evacuation. Subsequently, as the evacuation preparation time concludes, evacuation congestion occurs among the higher floor individuals, and the speed of movement in the staircases slows down.

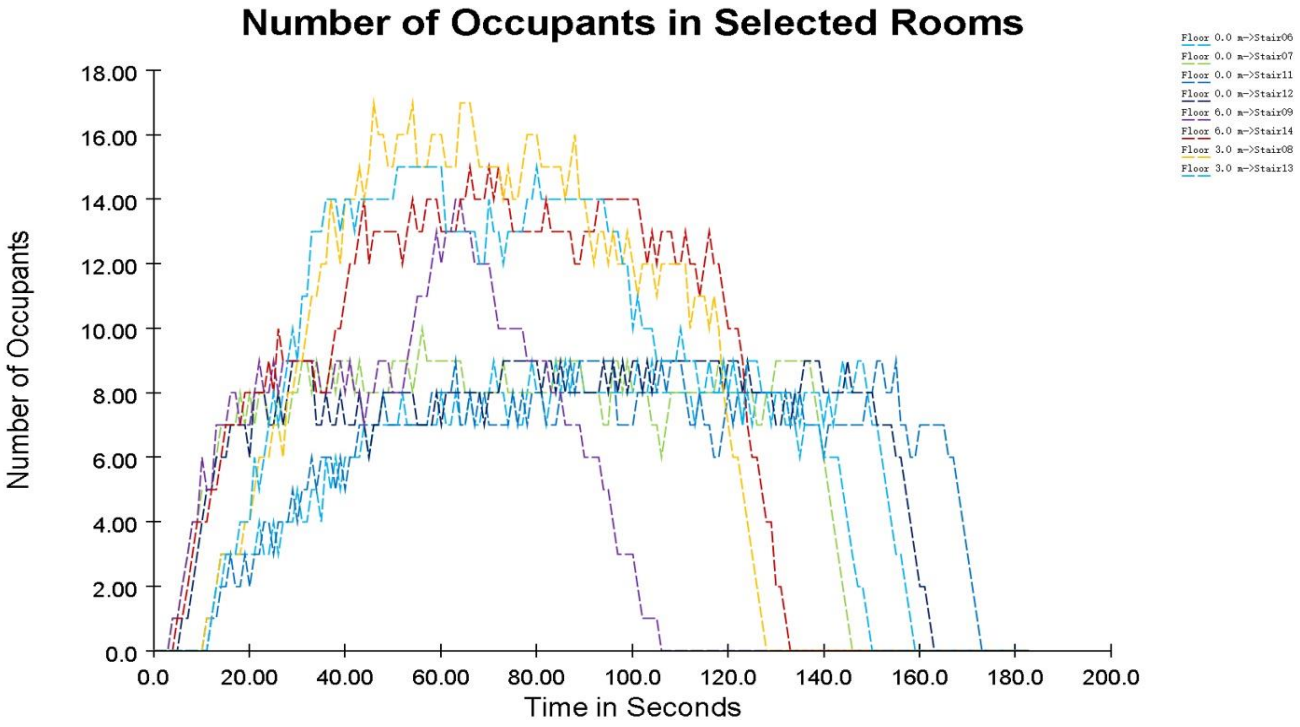

Figure 5.Graph for Scenario 1

Scenario 2 starts with a fire on the 2nd floor, and Figure 4 shows that the total evacuation time in Scenario 2 is 157 seconds. With the fire starting on the 2nd floor and an evacuation preparation time of 120 seconds for the 1st floor, the overall evacuation effectiveness is significantly improved. The trend of the overall curve change is the same as in Scenario 1.

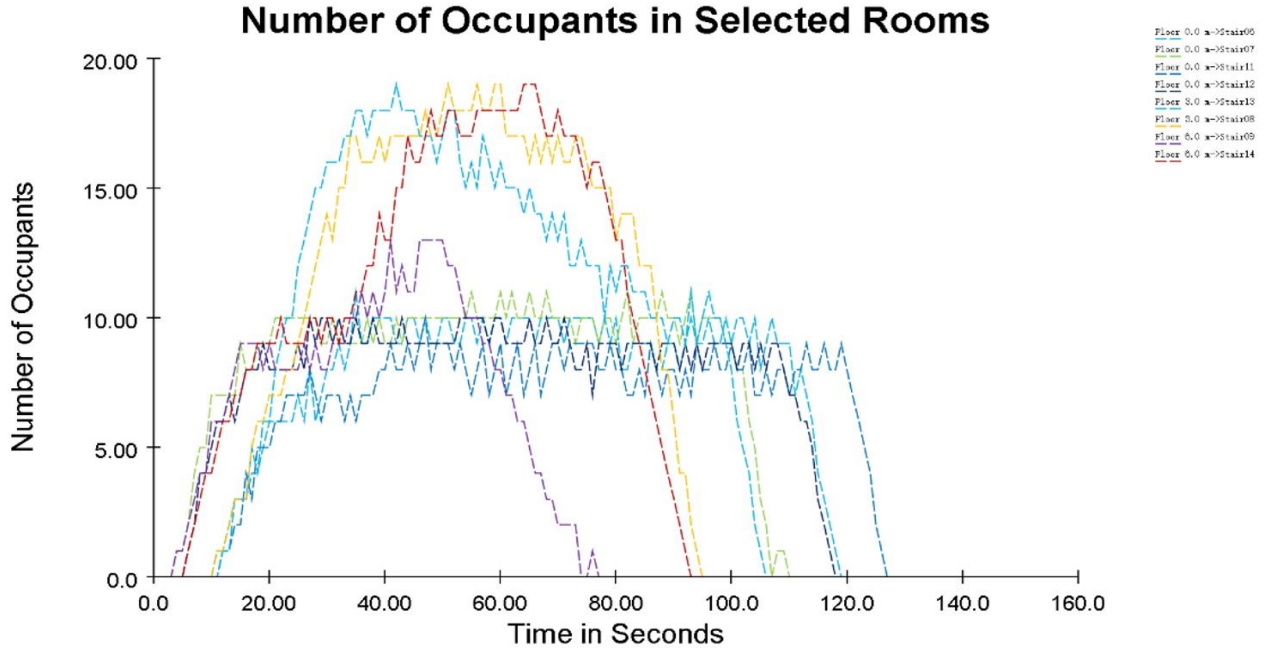

Figure 6. Graph for Scenario 2

Scenario 3 begins with a fire on the 3rd floor, resulting in a total evacuation time of 127 seconds for Scenario 3, a reduction of 28% in overall time. The trend in the overall curve change is similar to that in Scenario 1.

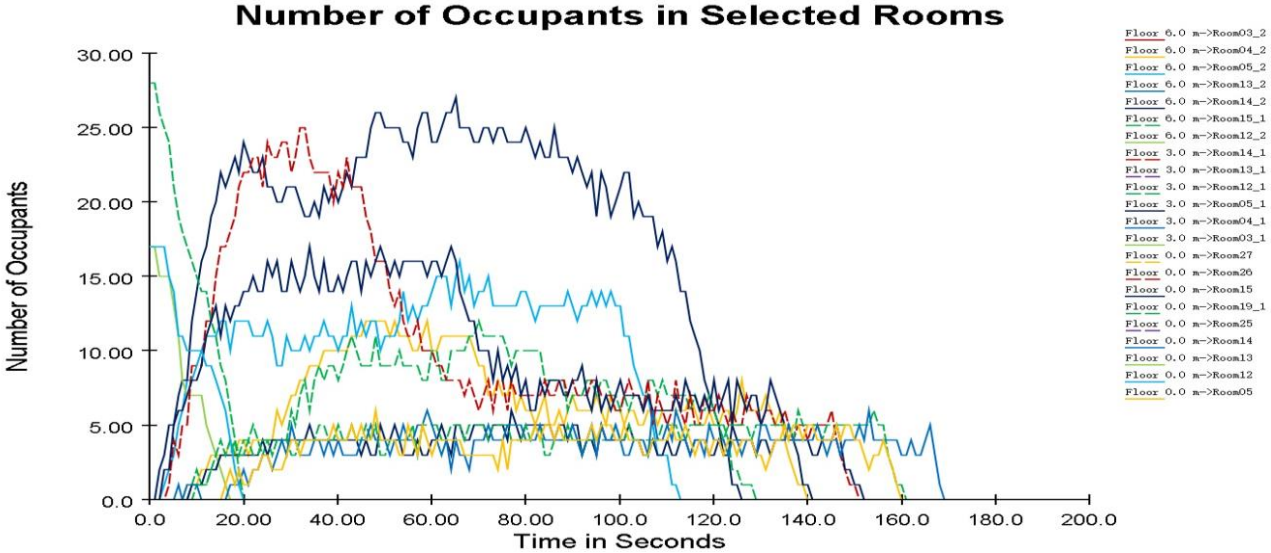

Figure 7. Graph for Scenario 3

These results demonstrate the impact of the fire's location and the evacuation preparation time on the overall evacuation process. Especially, a fire occurring on higher floors (e.g., Scenario 3), or a longer evacuation preparation time (e.g., Layer 1 of Scenario 2), tends to reduce evacuation time. Such analysis provides important insights for the fire safety design and evacuation planning of buildings.

5. CONCLUSION

This study employs Pathfinder to simulate the evacuation of staff in the event of a fire in a four-story school cafeteria. Two working conditions were set to investigate the impact of staircase width on personnel evacuation, and it was found that wider staircases can effectively reduce staff shortages. However, it is revealed that in the evacuation process, the main and side staircases in each floor are prone to forming an 'arch-like' congestion, leading to pushing and shoving among individuals. If evacuation direction is poor, leading to the formation of an 'arch,' this can result in trampling incidents, seriously impacting the safety of life and property of teachers and students. However, since this paper studies only a single factor, it cannot meet evacuation standards alone and recommends combining other influencing factors for improvement.

Based on the results of investigating the impact of staircase width on staff evacuation in a fire situation in a four-story school cafeteria using Pathfinder, the following improvement measures can be proposed:

In conclusion, this study emphasizes the importance of a comprehensive approach to improve evacuation safety and efficiency in educational settings. Expanding staircase widths and adding emergency staircases can significantly reduce bottlenecks and speed up evacuations. Optimizing evacuation routes with clear signage and lighting, coupled with regular evacuation drills, can prepare teachers and students for emergency situations. Strengthening command and management during evacuations is crucial to prevent confusion and congestion. A multifaceted evacuation strategy that considers building structure, population density, and fire location is essential for a thorough plan. Upgrading emergency facilities and equipment, such as lighting, signage, and fire extinguishers, enhances evacuation efficiency. Lastly, utilizing information and communication technology, like mobile apps for evacuation routes and safety information, can effectively manage emergencies. These measures collectively provide a robust framework for ensuring the safety of individuals in educational institutions during crises.

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