Research on Elevator Coordinated Evacuation Strategies in High-Rise Teaching Buildings

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Abstract. Building evacuation is an integral part of public safety. This paper used Pathfinder software to simulate coordinated elevator evacuation in high-rise teaching buildings, analyzing its impact on evacuation efficiency. The study shows that the higher the floors, the more prominent the role of elevators becomes. In a 19-story building, using a direct elevator strategy is most effective, reducing evacuation time by 135.2 seconds. This paper provides optimization strategies for coordinated elevator evacuation in high-rise teaching buildings, which are significantly important for enhancing the safety evacuation performance of teaching buildings.

Keywords: High-rise teaching building, Evacuation, Elevator stopping, Staircase, Simulation.

1 Introduction

Building evacuation, as an integral part of the public safety system, is of undeniable importance. From a national perspective, effective building evacuation strategies are crucial for responding to emergencies and ensuring the safety of the people. In specific building design, especially for densely populated areas such as teaching buildings and office buildings, evacuation design is directly related to everyone's life safety. Taking teaching buildings as an example, as one of the most densely populated buildings in schools, evacuation work becomes particularly important in the event of emergencies such as fires and earthquakes. In recent years, there have been numerous cases of casualties and property losses due to improper evacuation. For instance, the Bronx apartment fire in New York City, which resulted in 17 deaths and dozens of injuries due to excessive smoke and inability to evacuate in time, serves as a stark reminder that evacuation work in densely populated places must not be overlooked and must be given high priority and continuous improvement.

In recent years, research on high-rise building evacuation has shown a trend of diversification and deepening. With the acceleration of urbanization and the continuous increase in the number of high-rise buildings, the issue of evacuation in high-rise buildings has attracted increasing attention. High-rise building evacuation research mainly focuses on evacuation time, evacuation route planning, evacuation efficiency, and

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personnel safety within the building. The research content covers the establishment of evacuation models, evacuation simulation, analysis of evacuation behavior characteristics, and other aspects, with simulation and other methods widely used in research methods. Yan Zheng and others used Pathfinder software to simulate typical fire scenarios in the Yangtze River International Conference Center and found that by reasonably utilizing stairs, elevators, and refuge floors, the evacuation time during nighttime fires can be significantly reduced to only 36.6% to 55.3% of unorganized evacuations [1]; Gian Caleb Michealangelo and others used Pathfinder software to simulate the evacuation process and time of three typical high-rise residential buildings in Malaysia, recognizing the impact of high personnel density on evacuation time [2].

Teaching building evacuation research primarily focuses on aspects such as students' evacuation behavior in emergencies [3], evacuation efficiency [4], and the configuration of evacuation facilities [5]. Yan Cui and colleagues used Pathfinder software to establish a teaching building model, analyzed congestion issues during the evacuation process, and proposed reasonable evacuation route planning suggestions to alleviate the pressure of evacuation in high-rise corridors [6]. Alac Ruken developed a framework that integrates mathematical modeling, Building Information Modeling (BIM), and Agent-Based Modeling (ABM) to plan the location of safe evacuation exits in school buildings, which can improve the evacuation time of school buildings by about 10% [7].

Research on the involvement of elevators in evacuation mainly focuses on the operation strategies of elevators in emergencies, evacuation efficiency, and safety [8]. Gravit M. V. and others simulated scenarios where elevators are used as the main evacuation route in high-rise buildings and compared them with stairway evacuations, finding that reasonable elevator use and management strategies can significantly reduce evacuation time [9]. Minegishi Yoshikazu proposed an evacuation strategy that allows able-bodied individuals and those with mobility impairments to use elevators together without discrimination and discussed the feasibility of this strategy [10].

In Summary, current research on stair and elevator coordinated evacuation strategies is in-depth and comprehensive, with a small number of results focusing on the impact of factors such as the number of personnel and floors on evacuation efficiency during coordinated evacuation [11]. Based on this, this paper used Pathfinder software to establish a coordinated evacuation model for stairs and elevators in high-rise teaching buildings, fully exploring the relationships between the number of personnel, building height, evacuation time, elevator operating range, and the optimal direct floor for elevators. Subsequently, different evacuation strategies were simulated, and the stopping method of elevators in the strategies were studied for optimization.

2 Methodology

2.1 Research Object

This paper selected the second district of a high-rise comprehensive teaching building within a certain university as the research subject, as shown in Figure 1. The building, constructed in 2003, has a variety of functions and a complex structure, consisting of 10 floors with each floor from the first to the ninth being 4.2 meters high. The tenth floor features a pitched roof, and the total building height is 48.5 meters. The standard floor plan is depicted in Figure 2, which includes 8 small classrooms on each floor, a large classroom on the west side, restrooms, a teacher's lounge, and other ancillary rooms. The entire building is equipped with 4 staircases and 4 evacuation elevators, with safety exits distributed on both the east and west sides of the ground floor.

Fig. 1. Comprehensive Teaching Building

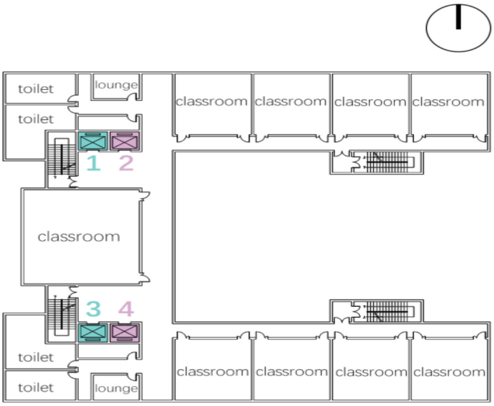

Fig. 2. Standard Floor Plan (Painted by the author)

2.2 Simulation Parameter Settings

In Pathfinder software, when the Steering mode was selected, the default behavior was for individuals to evacuate towards the nearest exit.

The artificially set parameters in the evacuation model that affect evacuation time mainly include the settings of safety exit parameters, crowd parameters, and evacuation behavior settings. For safety exit settings, in accordance with the teaching building's conditions, the west exit is 7.8 meters wide, and the east exit is 6.4 meters wide. Each classroom door is 1.2 meters wide; the stairs are 1.5 meters wide, and the elevator attribute parameters are shown in Table 1.

Through actual surveys, the types of evacuating personnel are mainly students and teachers, including a small number of security and cleaning staff. The number of people was set based on the maximum capacity and actual usage of different rooms in the teaching building. Classrooms were the main areas where people gather, and in the simulation, the number of people in the classrooms was set to full capacity. The ground floor lobby was set with 2 security and cleaning personnel, and the tenth floor was an activity space with lower utilization within the teaching building. Due to the lower frequency of use on this floor, no evacuating personnel were set in the simulation. There was a total of 5048 people in the entire building, consisting of 2524 males and 2524 females. Considering the gender ratio of male and female students and the different physical conditions between teachers and students, different movement speeds and shoulder widths for personnel were set, as shown in Table 2.

Table 1. Building Elevator Attribute Parameters (Created by the author)

Parameter	Reference Value
Maximum Capacity (people)	18
Motion Acceleration (m/s^2)	1.2
Maximum Speed (m/s)	2.5
Door Open Duration (s)	7
Door Switching Delay Time (s)	5

Table 2. Preset Personnel Parameter Table (Created by the author)

Personnel Type	Gender	Shoulder Width (cm)	Walking Speed (m/s)	Number of People
Students	Male	52	1.35	2484
	Female	46	1.215	2484
Teachers and Other Personnel	Male	52	1.1	40
	Female	46	1	40

2.3 Simulation Evacuation Strategies

The efficiency of evacuation in high-rise buildings is closely related to their inherent attributes, such as stair width and elevator acceleration, but is also influenced by the height of the building and the number of occupants. To explore the impact trends of these two factors on evacuation time under different evacuation strategies, this paper set up three different building height scenarios for simulated evacuations: 5-story, 10-story, and 19-story buildings. The theoretical model established through Pathfinder is shown in Figure 3. When the building is 5 stories high, the total height is 21 meters, classified as a multi-story building, with a total of 2,612 occupants; when the building is 10 stories high, the tenth floor is considered a flat roof, with a total height of 42 meters, classified as a second-class high-rise building, with a total of 5,048 occupants, among which occupants from the first to the ninth floors are included in the evacuation; when the building is 19 stories high, the height is 79.8 meters, classified as a first-class high-rise building, with a total of 10,529 occupants, among which occupants from the first to the eighteenth floors are included in the evacuation.

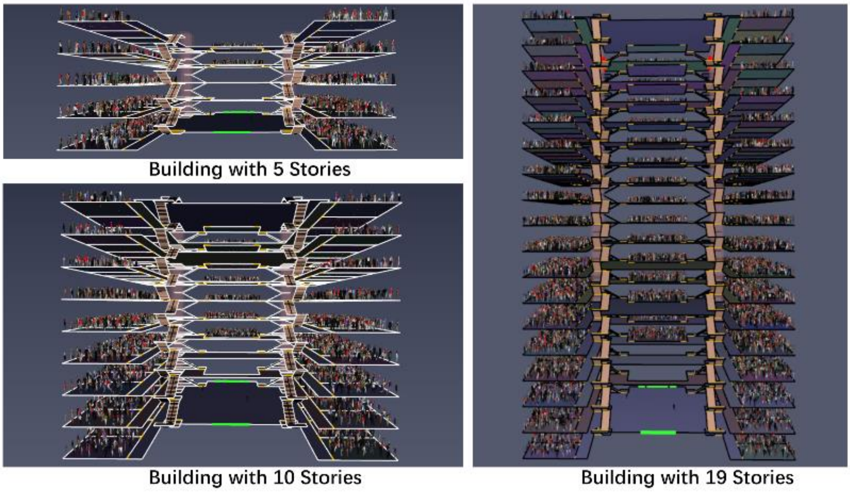

Fig. 3. Pathfinder Theoretical Model (Photographed by the author)

This paper proposed three different evacuation strategies to investigate the impact of the number of occupants and building height on parameters such as total evacuation time in different evacuation scenarios.

Strategy 1: Staircase as the sole evacuation route. Except for the occupants on the ground floor who directly left the building through external evacuation exits, occupants on other floors used only the stairs for evacuation.

Strategy 2: Elevator direct evacuation strategy. A specific floor of the building was designated as the direct floor, meaning the elevator was only allowed to stop at the ground floor and the direct floor to transport occupants to the ground floor.

Strategy 3: Elevator zoned evacuation strategy. The elevator operating range was divided into three parts: lower zone, middle zone, and upper zone, meaning the elevator was only allowed to transport occupants within a specific area. (see Figure 4). When the building is 5 stories, the lower zone is floors one to two, the middle zone is floor three, and the upper zone is floors four to five; when the building is 10 stories, the lower zone is floors one to three, the middle zone is floors four to six, and the upper zone is floors seven to nine (the tenth floor is not included in the count); when the building is 19 stories, the lower zone is floors one to six, the middle zone is floors seven to twelve, and the upper zone is floors thirteen to eighteen (the nineteenth floor is not included in the count).

The different scenarios within the above strategies are numbered for subsequent result analysis and discussion, as shown in Table 3.

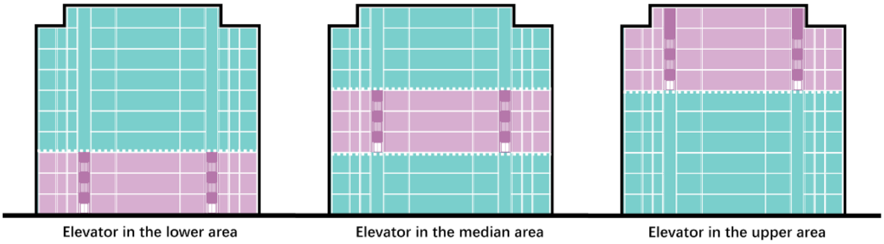

Fig. 4. Elevator Zoned Evacuation Strategy (Painted by the author)

Table 3. Scenario Numbering (Created by the author)

Number	Scenario
1	Five-story building with elevator direct evacuation
2	Ten-story building with elevator direct evacuation
3	Nineteen-story building with elevator direct evacuation
4	Five-story building with elevator zoned evacuation
5	Ten-story building with elevator zoned evacuation
6	Nineteen-story building with elevator zoned evacuation

3 Results and Discussion

3.1 Elevator Direct Evacuation Strategy

Figure 5 illustrated the change in evacuation time for elevator direct evacuation strategy increases.

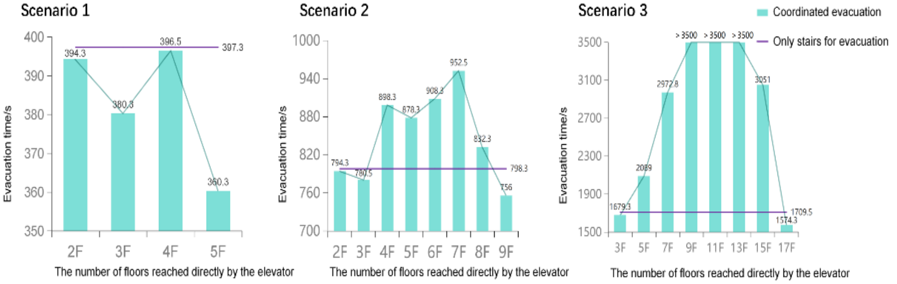

Fig. 5. Evacuation Time for Elevator Direct Evacuation Strategy (Painted by the author)

Scenario 1: When the direct floor was at the fifth floor, the shortest evacuation time was achieved, at 360.3 seconds, saving 37 seconds.

Scenario 2: When the direct floor was at the ninth floor, the shortest evacuation time was achieved, at 756 seconds, saving 42.3 seconds.

Scenario 3: When the direct floor was between the ninth and thirteenth floors, the total evacuation time exceeded 3500 seconds. When the direct floor was at the seventeenth floor, the shortest evacuation time was achieved, at 1574.3 seconds, saving 135.2 seconds.

During coordinated evacuation with elevators, as the direct elevator floor rises, the evacuation time shows a trend of initially increasing and then decreasing. This is because when the direct elevator floor was in the lower part of the building (2F or 3F), the evacuation time through the stairs was less than that of using the elevator. In the early stages of evacuation, there was significant congestion at the rest platform in front of the elevator and staircase, and people choosing to evacuate via the elevator can alleviate the congestion. After the congestion cleared, the remaining evacuees opted to use the stairs. Since the second floor was closer to the evacuation exit than the third floor, the initial congestion was less, and after two round trips without congestion, the remaining evacuees chose to use the stairs, resulting in lower elevator utilization. Therefore, when the direct floor was on the second floor, it can reduce the overall evacuation time, but the reduction was relatively small. The time saved for buildings with 5, 10, and 19 floors were 3 seconds, 4 seconds, and 11.5 seconds, respectively. The higher the total number of building floors, the more time was saved.

When the direct floor was in the middle of the building, there were more people above the direct floor, and the distance to the evacuation exit was relatively far. The elevator evacuation speed was higher than that of the stairs, and most people chose to wait for the elevator. However, due to the limited capacity of the elevator, the evacuation efficiency was limited, which may increase the evacuation time, even exceeding the time when the staircase was the only evacuation route.

When the direct floor was in the upper part of the building, there were fewer people above the direct floor, and the distance to the evacuation exit was relatively far. The elevator evacuation speed was higher than that of the stairs, and most people above the direct floor chose to wait for the elevator. When the evacuation times for both methods were close, the total evacuation time was greatly reduced.

From the simulation results, the effectiveness of the elevator direct evacuation strategy was closely related to the total number of building floors and the choice of the direct floor. When the building had fewer floors, the evacuation distance was relatively short, and the advantage of the elevator was not significant. However, as the number of building floors increased, the role of the elevator in evacuation became more prominent. When the direct floor was chosen close to the top of the building, the efficiency of coordinated elevator evacuation was the highest. When the building was 19 floors and the direct floor was 17, the efficiency of coordinated elevator evacuation was 8% higher than that of evacuation using stairs only. This was because people above the direct floor can evacuate quickly via the elevator, while those below the direct floor can use the stairs. When the evacuation times for both methods were close, the total evacuation time can be reduced by 135.2 seconds.

3.2 Elevator Zoned Evacuation Strategy

Figure 6 presented the change curve of evacuation time for elevator direct evacuation strategy.

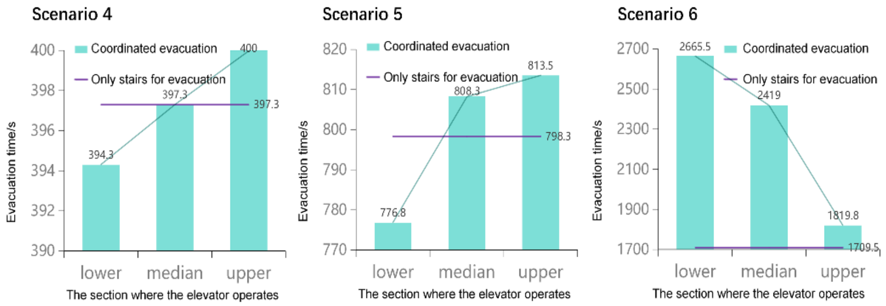

Fig. 6. Evacuation Time for Elevator Zoned Evacuation Strategy (Painted by the author)

Scenario 4: When the elevator operates in the lower zone, the shortest evacuation time was achieved at 394.3 seconds, saving 3 seconds compared to other methods, although the degree of time reduction was relatively low.

Scenario 5: When the elevator operates in the lower zone, the shortest evacuation time was achieved at 776.8 seconds, saving 21.5 seconds. The evacuation situation was similar to when the elevator direct floor is on the third floor.

Scenario 6: When the elevator operates in the upper zone, the shortest evacuation time, although improved, was 1819.8 seconds, still exceeding the evacuation time when the staircase was the only evacuation route. This was because as the number of floors increases, the number of floors contained within each zone also increases. For individuals, the elevator evacuation speed was faster than the stairs, leading most people to choose waiting for the elevator for evacuation. However, due to the limited carrying capacity of the elevator, the evacuation efficiency was constrained, significantly increasing the waiting time for people, and the total evacuation time may even exceed that of using the staircase as the sole evacuation route.

Therefore, for first-class high-rise buildings (where the building height is excessively high), the elevator zoned evacuation strategy is not recommended due to the inability to accurately predict the operation status of the elevators.

The elevator zoned evacuation strategy aims to improve evacuation efficiency by dividing the building into different zones and assigning corresponding elevators for evacuation. However, as the simulation results show, this strategy was not always effective. In buildings with a high total height and numerous floors, where each zone contained a large number of floors, most people tended to wait for the elevator for evacuation. Due to the limited carrying capacity of the elevators and the unpredictable operation status, the evacuation efficiency decreased.

Moreover, in the elevator zoned evacuation strategy, when the elevator operates in the middle and upper zones, the carrying capacity and operational efficiency of the elevators were also significant factors affecting the evacuation time. At the beginning of the evacuation, after the elevator made a round trip and reached the bottom floor of the zone, congestion occurred at the rest platform in front of the elevator and staircase, preventing people inside the elevator from exiting promptly, thus affecting the efficiency of the elevator evacuation. When formulating evacuation strategies, it was necessary to consider how to avoid or mitigate such congestion.

3.3 Strategy Optimization

From the analysis above, it can be observed that in the elevator zoned evacuation strategy, there was a situation where congestion occurred at the rest platform in front of the elevator and stairs, preventing people inside the elevator from evacuating promptly, which affected the overall evacuation efficiency. To address this issue, this paper proposed three different elevators zoned stopping methods, starting from the elevator's operating mechanism, to explore the possibility of maximizing the optimization of the elevator zoned evacuation strategy under different zoned stopping methods. The following simulations of the optimization strategies were only for the case when the building has 10 floors (elevator numbering is shown in Figure 2).

Strategy 4: Elevator 1 and 3 operated in the lower zone, while Elevator 2 and 4 operated in the upper zone (referred to as Scenario 7).

Strategy 5: Elevator 1 and 3 operated in the lower zone, while Elevator 2 and 4 operated in the middle zone (referred to as Scenario 8).

Strategy 6: Elevator 1 and 3 operated in the middle zone, while Elevator 2 and 4 operated in the upper zone (referred to as Scenario 9).

The simulation results can be seen in Figure 7.

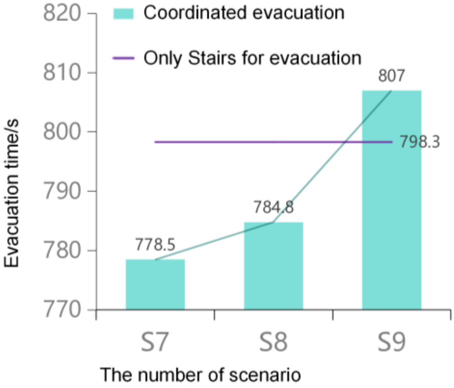

Fig. 7. Evacuation Time for Optimized Strategies (Painted by the author)

The optimized elevator zoned evacuation strategy was generally more effective than the original strategy. This was largely due to the reduction in congestion at the rest platform in front of the elevator and stairs, leading to an increased elevator utilization rate.

4 Conclusions

(1) As the number of building floors increases, the role of elevators in the evacuation process becomes increasingly significant. In this study, the elevator direct evacuation strategy was most effective in a 19-story building, reducing time by 135.2 seconds.

(2) In high-rise teaching buildings, employing an elevator direct evacuation strategy can significantly improve evacuation efficiency. When the direct floor was chosen close

to the top of the building, the effect of coordinated elevator evacuation was most pronounced, increasing evacuation efficiency by 8%.

Although this study has achieved certain results, there are still some limitations. Due to the limited number and diversity of actual cases, it may not fully cover all possible situations. In the future, the research scope of actual cases can be expanded to improve the universality and reliability of the research findings. Additionally, the optimization space for coordinated evacuation of stairs and elevators, such as the control of elevator scheduling by intelligent algorithms and IoT technology, will be a focus of subsequent work.

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