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Analysis of Safety Evacuation Rules for Elderly and Children in High rise Hotel

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Abstract

High rise hotels are densely populated and have complex ignition sources. Once a fire occurs, it can cause serious casualties and property damage. The impact of a fire is greater on special groups such as the elderly and children who move slowly. At present, research mainly focuses on the impact of high-rise building structures on evacuation consequences, but there is little research on the safety evacuation consequences of elderly and children in high-rise hotels, as well as the behavior of people in groups during the safety evacuation process. Therefore, we propose to use Pathfinder software to simulate three scenarios for the elderly and children in high-rise hotels. Scenario 1 involves arranging the elderly and children on higher floors, Scenario 2 involves arranging them on middle floors, and Scenario 2 involves arranging them on lower floors. We further provide three types of personnel pairing schemes for each scenario, namely: no one pairing, two people pairing, and three people pairing. Through simulation analysis, we found that placing elderly and children with lower mobility on lower floors resulted in the shortest safe evacuation time; The evacuation time for solo actions without companionship is the shortest, followed by two people in groups, and the safety evacuation time for three people in groups is the longest. Our research findings have significant implications for improving the evacuation efficiency of personnel in fire scenarios.

Key Words: *High Rise Hotel, Companionship, Elderly and Children, Pathfinder.*

1. INTRODUCTION

With the rapid development of the Chinese economy, the number of high-rise hotels built is increasing, and the building structure is also becoming more complex. With the increase of fire risk, scale, and more serious consequences of casualties. In recent years, about 70% of casualties have been closely related to fire accidents. Therefore, it is urgent to pay attention to and solve the safety evacuation problem of high-rise hotels. Rapid, effective, and safe evacuation of personnel has become a research focus for many experts and scholars.

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Chen et al. (2020) proposed an overall layout strategy for high-rise nursing homes and the optimal use of elevator staircase combinations during emergency evacuation processes [1]. The results indicate that compared to using elevators or stairs alone, the evacuation combination of elevators and stairs is more effective. Increasing the number and speed of elevators can reduce evacuation time. Classifying elderly people into different floors based on their physical condition can reduce evacuation time compared to randomly assigning them. Spearpoint et al. (2024) used two tools, Pathfinder and Macroscopic, to simulate and analyze their effects on the evacuation routes of high-rise buildings [2]. Mossberg et al. (2021) conducted a questionnaire study and conducted evacuation experiments on high-rise buildings with elevators, and found that people usually choose elevators for evacuation [3]. Even if they are closer to the evacuation stairs, the flashing of evacuation signs will make people more likely to choose elevators for evacuation. Cao et al. (2021) proposed an evacuation model that determines the pressure level of evacuees based on specific surrounding environmental values, enabling them to perceive fire risks and take action to deal with fire hazards [4]. This study focuses on the impact of pressure factors on crowd evacuation performance. Zheng et al. (2024) analyzed the impact of personnel distribution on the safe evacuation of high-rise buildings [5]. The research results showed that unorganized evacuation can lead to a single person taking the wrong evacuation route, forming a huge congested area and reducing the efficiency of evacuation. Komatsu et al. (2016) proposed an automatic evacuation guidance scheme using mobile nodes of evacuees (such as smartphones), where each mobile node attempts to navigate its evacuees by providing evacuation routes [6]. It can also track the actual evacuation route by regularly measuring the location of evacuees. The proposed scheme automatically estimates road congestion based on the difference between the displayed evacuation route and the actual evacuation route, and then recalculates alternative evacuation routes.

When a disaster occurs, the trapped population on site will hope to escape as early as possible, and personnel will escape at a faster speed than usual. At the same time, there is a significant interaction force between people, with the most obvious being the act of companionship. This may lead to waiting in place for friends or family during the evacuation process, causing congestion in small spaces in order to leave the scene together. In crowded environments, the squeezing pressure between people will rapidly increase, leading to a slowdown in evacuation speed and making evacuation routes congested. This phenomenon is not uncommon and is an important reason for the overall low evacuation efficiency. However, current research has shown that evacuation methods for personnel are usually set on a per capita basis, without considering the group behavior that is highly likely to occur in critical situations.

This article uses Pathfinder software for evacuation simulation to explore the impact and patterns of personnel's companion behavior on evacuation during the evacuation process, in order to improve evacuation efficiency and reduce casualties in fire scenarios.

2. INTRODUCTION TO SIMULATION SOFTWARE AND RESEARCH MODEL

2.1 Research Model

According to the research objectives of this paper the following research model has been established. The simulation section includes three scenarios, each of which considers three different situations, as shown in Figure 1.

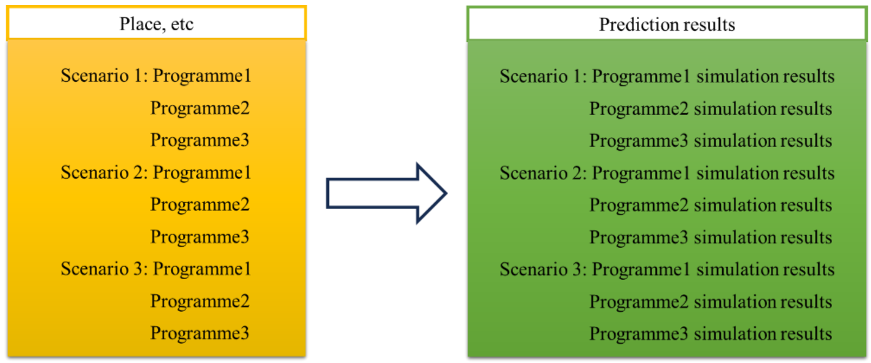

Figure 1: Research model

2.2 Simulation Software

Pathfinder is a simulator based on personnel evacuation and movement simulation. It provides users with a graphical user interface for simulation design and operation, as well as 2D and 3D visualization tools for analyzing results. The Pathfinder software includes two modes, Steering mode and SFPE mode. In Steering mode, personnel can evacuate independently while avoiding collisions with other personnel. Software can effectively simulate the grouping of evacuees，therefore, this paper uses pathfinder software to simulate the evacuation of people in groups.

3. EVACUATION MODEL AND SIMULATION PARAMETER SETTINGS

3.1 Evacuation Model

The plan view of the high rise hotel is shown in Figure 2. There are two staircases in the hotel, each with a width of 1.25 meters, three safety exits, and an evacuation walkway with a width of 3 meters. Evacuation corridors are unobstructed.

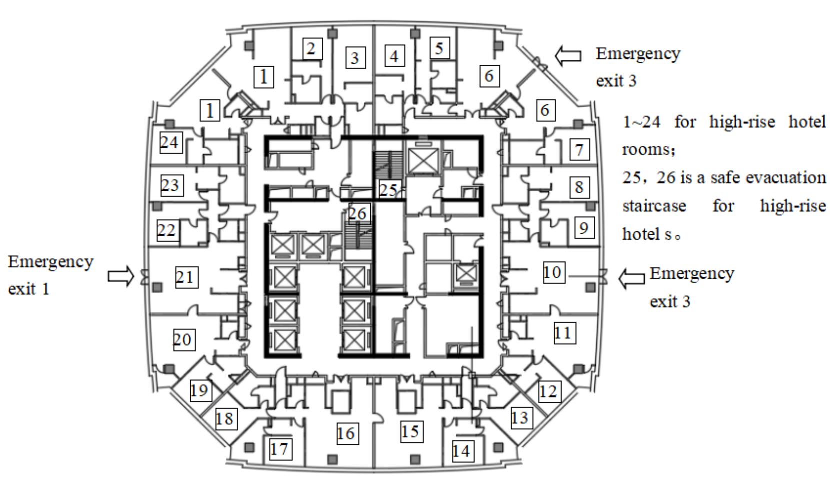

Figure 2: High rise hotel floor plan

The hotel has 24 rooms on the 1st to 8th floors, with a total of 216 rooms. Each floor has a height of 3 meters. The vertical height of the hotel is 24 meters, and the three-dimensional view is shown in Figure 3.

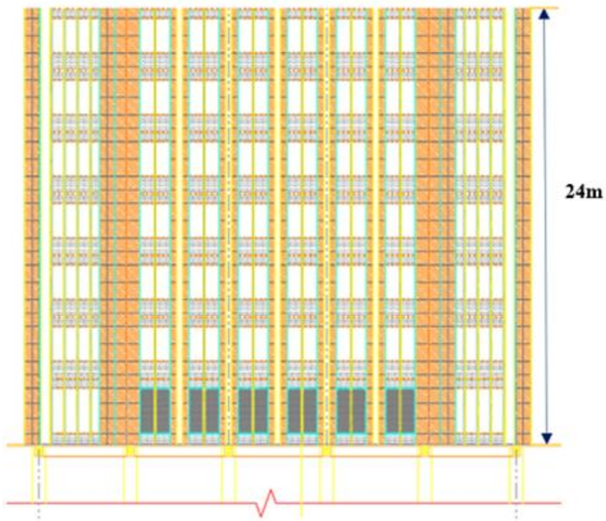

Figure 3: Elevations of high rise hotel

3.2 Basic Parameter Settings for Evacuating Pedestrians

According to the Chinese Code for Fire Protection Design of Buildings (GB50016-2014), elevators should not be considered as safety evacuation facilities, Ordinary elevators will automatically cut off the power supply in the event of a fire, and are not smoke proof, fire proof, or waterproof, making them unsafe evacuation facilities [7]. The fire elevator can serve as a fire evacuation route after a fire occurs, but currently it can only be controlled and used by professional firefighters. In the emergency control phase, it will not be able to serve as a means of evacuation for residents.

3.2.1 Evacuate Pedestrian Types

Based on the actual situation of high-rise hotels, the evacuation personnel are divided into four categories: adult males, adult females, children, and the elderly. The Chinese Children's Development Outline (2021-2030) stipulates that children are aged 0-14 years old. The Law of the People's Republic of China on the Protection of the Rights and Interests of the Elderly stipulates that elderly people are over 60 years old.

The total number of evacuees in the evacuation simulation experiment was 388. According to the statistical results of literature [8], the number of various types of personnel was set, with adult males accounting for 35%, adult females accounting for 35%, elderly people accounting for 20%, and children accounting for 10%. Therefore, the specific number of people in this model is set to 136 adult males, 136 adult females, 78 elderly people, and 38 children. Place people with lower mobility, namely the elderly and children, in the lower, middle, and upper floors respectively. Due to practical considerations, children are not allowed to live alone, so a family of three consisting of children and adult males, adult females, and the elderly are arranged to be located on different floors.

3.2.2 Evacuate Pedestrian Speed

Based on experimental results [8] and references [9-10], considering the particularity of pedestrian evacuation, Table 1 provides characteristic parameters of evacuation speed, height, and shoulder width for the elderly, children, adult males, and adult females. The specific parameters are shown in Table 1.

Table 1: Speed and body characteristic parameter settings for evacuating pedestrians

Personnel Type	Speed（m/s）	Height（m）	Shoulder Width（m）
Children	0.77, [11]	1.30	0.30
The old	0.92, [12]	1.60	0.50
Adult male	1.19, [13]	1.70	0.50
Adult female	0.85, [13]	1.60	0.45

3.2.3 Scenario Settings

In order to achieve the research objectives, this article has set up three scenarios based on the elderly and children on different floors, and in each scenario, three plans have been set up according to the companionship behavior of personnel.

According to the research objectives, the scenario settings as shown in Table 2.

(1)Scenario 1:

The elderly and children are in the high-rise, with 78 elderly and 38 children on the 6th to 7th floors. Considering that children should be with adults, 38 adult males and 38 adult females are also on the 6th to 7th floor.

(2) Scenario 2:

The elderly and children are in the middle layer. 78 elderly people and 38 children are all on floors 4-5.

(3) Scenario 3:

The elderly and children are on lower floors. 78 elderly people and 38 children are all on the 2nd to 3rd floors. Considering that children should be with adults, 38 adult males and 38 adult females are also on the 2nd to 3rd floors.

The detailed content of the script is shown in table 2.

Table 2: Specific situation of the scenario

scene	floor	children	the old	Adult male	Adult women
Scenario 1	1-3	38	78	38	38
	4-6	0	0	50	50
	7-8	0	0	48	48
Scenario 2	1-3	0	0	50	50

	4-6	38	78	38	38
	7-8	0	0	48	48
Scenario 3	1-3	0	0	50	50
	4-6	0	0	48	48
	7-8	38	78	38	38

It is common for family and friends to stay together in high-rise hotel residents. Therefore, there is also human companionship behavior in fire evacuation scenarios or other emergency situations. In the process of safe evacuation, there will be a leader in each group of people, and the rest of the team will search for the leader and approach him, and evacuate according to the evacuation direction chosen by the leader. Considering that there may be certain social or family relationships between companions, members may be too far away from each other or out of sight, and other members may experience a state of worry and anxiety, making it difficult to evacuate normally like a single person. The main difference between companion action and solo action lies in the phenomenon of waiting for outdated members.

This article will mainly focus on the companion behavior of adult males, adult females, and children in a family of three, and randomly assign groups of companions to various positions on the designated floor, ensuring that all group members are on the same floor. The remaining personnel evacuated in a single person mode without accompanying behavior. Study the impact of different numbers of companions on the evacuation time of personnel.

In the Pathfinder software, the Max Distance and Slowdown time can be set for group members of companions. If the distance between a member in a group and other members exceeds the "distance threshold", it will be considered that the member is disconnected from the entire team. Once the team triggers a disconnection state, the leader of the team's movement will slow down for a certain period of time to wait for the disconnected members to reconnect. To provide a more intuitive analysis of the impact of the number and type of companions on evacuation, three companion schemes were set for each scenario in Table 2. The specific schemes are shown in Table 3, with a critical spacing value of 1 meter and a deceleration waiting time of 3 seconds.

Table 3: Personnel companion optimization plan

Scheme	Companion or not	Type of Companion	Leaders
Scheme 1	No	No	No
Scheme 2	Yes	Adult males, children	Adult males
Scheme 3	Yes	Adult females, adult males, children	Adult males

In companion behavior, when the distance between the leader and other members of the same group exceeds the set distance threshold of 1 m, the leader reduces the forward speed for a certain period of time to wait for the disconnected members to reconnect. Both the target and reference individuals were selected as adult males for observation. If the evacuation speed of two people is the same and it can be observed from the picture that there is no crowding in their location, then they are in normal evacuation mode. From the above picture, it can be seen that at 103 seconds, the distance between the target personnel and the reference personnel is close. At 108 seconds, it can be observed that the position of the reference personnel has hardly moved, and it can be visually observed that the distance between the target personnel and the reference personnel has increased. This phenomenon is caused by the target personnel reducing their forward speed to wait for disconnected members to reconnect. As shown in Figure 4.

Figure 4: Showcase of companion behavior

4. EVACUATION SIMULATION

4.1 Scenario 1 Simulation Results

Scenario 1 involves placing a group of people with lower mobility on floors 1-3, following the previous personnel settings and considering different companionship situations, using pathfinder software for simulation to obtain the data in Tables 4, 5, and 6.

Table 4: Scenario 1: changes in safety evacuation time (a)

Staircase width / Companion	100 cm	105 cm	110 cm	115 cm	120 cm	125 cm	130 cm
Unaccompanied	449.8 s	435.0 s	410.8 s	392.8 s	368.8 s	354.3 s	339.8 s
Two people in company	445.3 s	434.3 s	415.3 s	400.8 s	384.8 s	363.0 s	347.0 s
Three people in company	442.5 s	436.0 s	420.0 s	398.8 s	381.3 s	365.5 s	353.0 s

Table 5: Scenario 1: changes in safety evacuation time (b)

Staircase width / Companion	135 cm	140 cm	145 cm	150 cm	155 cm	160 cm	165 cm
Unaccompanied	326.3 s	319.5 s	315.0 s	308.5 s	303.5 s	297.0 s	293.3 s
Two people in company	337.3 s	323.3 s	317.0 s	315.0 s	308.0 s	307.5 s	305.0 s
Three people in company	342.3 s	334.8 s	324.8 s	321.3 s	316.3 s	315.8 s	310.5 s

Table 6: Scenario 1: changes in safety evacuation time (c)

Staircase width / Companion	170 cm	175 cm	180 cm	185 cm	190 cm	195 cm	200 cm
Unaccompanied	295.5 s	290.5 s	284.5 s	290.0 s	282.3 s	288.8 s	282.0 s
Two people in company	298.3 s	293.5 s	294.8 s	297.3 s	291 s	295.8 s	289 s
Three people in company	305.5 s	306.3 s	310.0 s	300.0 s	302.5 s	298.5 s	296.0 s

Draw the evacuation time variation curve based on the data in the three tables above, as shown in Figure 5. Figure 5 shows the trend of evacuation time with the width of the stairs under different combinations of companions. The companionship behavior of personnel includes no one accompanying, 2 people accompanying, and 3 people accompanying. From the graph, it can be seen that the overall situation is that as the width of the stairs increases, the evacuation time in the world gradually decreases. The evacuation time of 2 people accompanying is greater than that of a single person, and less than that of 3 people accompanying.

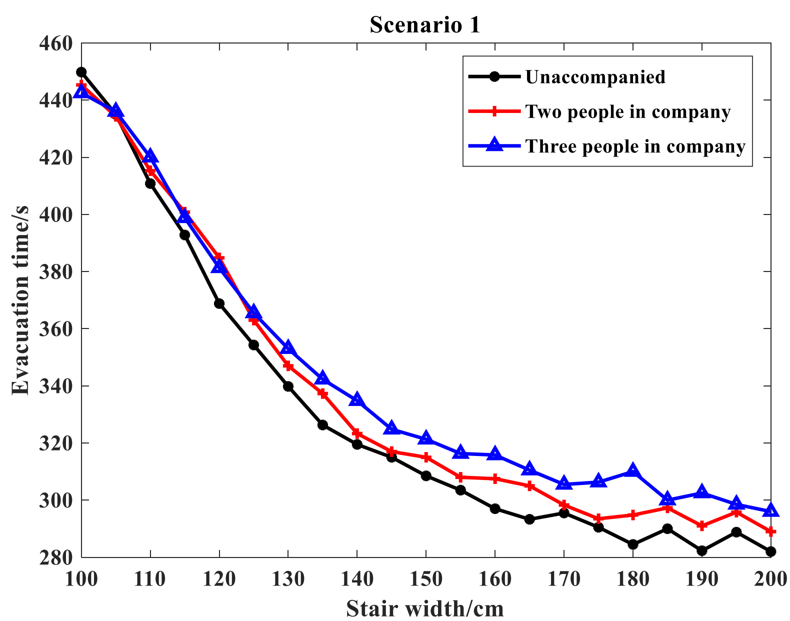

Figure 5: Diagram of safety evacuation time on floors 1-3 changing with the number of companions

4.2 Scenario 2 Simulation Results

Scenario 2 involves placing people with lower mobility on floors 4-6. There are three forms of personnel companionship. The width of the stairs changed from 100cm to 200cm, with an interval of 5cm between each change. Simulate using pathfinder, and the results are shown in Tables 7, 8, and 9.

Table 7: Scenario 2: changes in safety evacuation time (a)

Staircase width / Companion	100 cm	105 cm	110 cm	115 cm	120 cm	125 cm	130 cm
Unaccompanied	480.3 s	457.8 s	443.3 s	414.8 s	394.5 s	384.8 s	369.8 s
Two people in company	485.5 s	464.3 s	450.3 s	428.3 s	409.5 s	391.0 s	374.5 s
Three people in company	484.5 s	470.3 s	456.0 s	430.0 s	417.3 s	396.5 s	384.5 s

Table 8: Scenario 2: changes in safety evacuation time (b)

Staircase width / Companion	135 cm	140 cm	145 cm	150 cm	155 cm	160 cm	165 cm
Unaccompanied	355.8 s	351.5 s	342.5 s	334.8 s	333.0 s	325.8 s	326.0 s
Two people in company	363.8 s	353.3 s	345.0 s	340.3 s	332.0 s	329.3 s	325.8 s
Three people in company	374.3 s	362.8 s	372.3 s	354.5 s	348.5 s	343.5 s	339.0 s

Table 9: Scenario 2: changes in safety evacuation time (c)

Staircase width / Companion	170 cm	175 cm	180 cm	185 cm	190 cm	195 cm	200 cm
Unaccompanied	321.8 s	319.3 s	315.3 s	313.8 s	314.8 s	312.3 s	313.5 s
Two people in company	322.3 s	321.8 s	316.8 s	317.3 s	323.3 s	316.8 s	315.3 s
Three people in company	334.0 s	330.5 s	330.3 s	328.3 s	323.0 s	321.0 s	319.8 s

Draw the evacuation time variation curve based on the data in Tables 7, 8, and 9, as shown in Figure 6. From Figure 6, it can be seen that the evacuation time is much longer for three person and unmanned groups. Compared to two person groups, the evacuation time is much longer. The evacuation time for two person groups is relatively close, and the overall trend is that the evacuation time gradually decreases as the width of the stairs increases. Considering the actual evacuation situation, when the elderly and children are arranged on the 4th to 6th floors, it is best to evacuate with two people together.

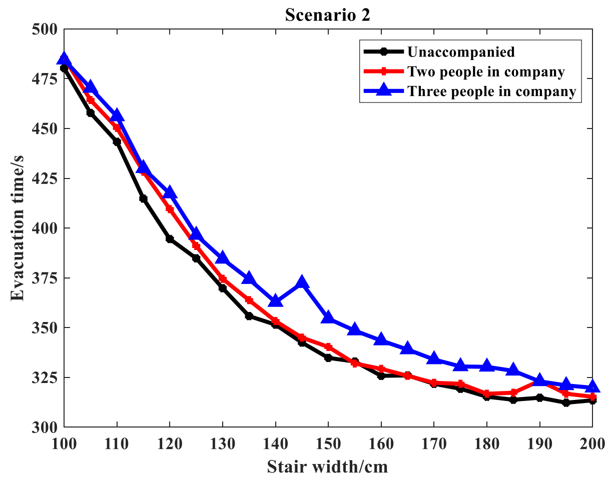

Figure 6: Schematic diagram of the variation of safety evacuation time on floors 4-6 with the number of accompanying personnel

4.3 Scenario 3 Simulation Results

Scenario 3 involves placing people with lower mobility on floors 6-8. There are also three ways for personnel to collaborate. The widths of the stairs are 100cm, 105cm, 110cm, 115cm, 120cm, 125cm, 130cm, 135cm, 140cm, 145cm, 150cm, 115cm, 150cm, 155cm, 160cm, 165cm, 170cm, 175cm, 180cm, 185cm, 190cm, 195cm, and 200cm respectively. The simulation results are shown in Tables 10, 11, and 12.

Table 10: Scenario 3: changes in safety evacuation time (a)

Staircase width / Companion	100 cm	105 cm	110 cm	115 cm	120 cm	125 cm	130 cm
Unaccompanied	484.3 s	465.5 s	441.3 s	417.8 s	402.8 s	383.0 s	368.8 s
Two people in company	488.5 s	464.3 s	448.0 s	427.5 s	410.5 s	386.5 s	373.5 s
Three people in company	488.3 s	476.3 s	451.8 s	435.3 s	413.5 s	401.3 s	382.0 s

Table 11: Scenario 3: changes in safety evacuation time (b)

Staircase width / Companion	135 cm	140 cm	145 cm	150 cm	155 cm	160 cm	165 cm
Unaccompanied	357.8 s	349.3 s	343.3 s	335.3 s	330.3 s	325.8 s	324.3 s
Two people in company	365.5 s	351.0 s	348.0 s	344.0 s	336.0 s	329.8 s	328.3 s
Three people in company	372.8 s	360.0 s	357.3 s	349.5 s	344.3 s	346.8 s	334.0 s

Table 12: Scenario 2: changes in safety evacuation time (c)

Staircase width / Companion	170 cm	175 cm	180 cm	185 cm	190 cm	195 cm	200 cm
Unaccompanied	319.8 s	322.0 s	317.5 s	316.0 s	308.5 s	311.3 s	309.3 s
Two people in company	324.3 s	327 s	323.8 s	316 s	314 s	312.3 s	314 s
Three people in company	334.3 s	330.3 s	340.8 s	329.0 s	326.5 s	327.5 s	325.0 s

Draw a comparative analysis chart based on the data from the three tables above, as shown in Figure 7. The evacuation time for unmanned groups is similar to that of a group of two people, which is shorter than that of a group of three people. When the width of the stairs decreases from 100cm to 140cm, the evacuation time decreases significantly. The width of the staircase changes from 140cm to 200cm, and the overall trend of evacuation time is gradually decreasing, but it is relatively flat. Although the overall evacuation time is relatively short without companionship, when there are elderly and children, companionship evacuation is a situation that is in line with objective facts. Therefore, when the elderly and children are arranged on the 6th to 8th floors, a two person companionship is the best evacuation plan.

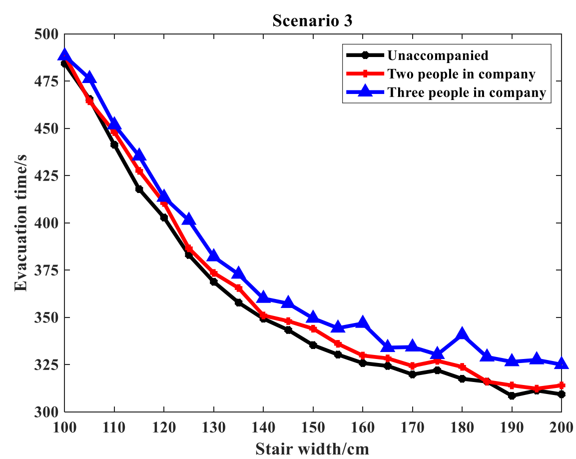

Figure 7: Schematic diagram of the variation of safety evacuation time on floors 6-8 with the number of accompanying personnel

4.4 Summary of the Optimization Effect of Personnel Pairing Plan

According to Figures 5, 6, and 7, as the number of people in groups increases on the same floor, the average evacuation time for two person groups and three person groups increases. Observing the three curves of the three scenarios, it can be seen that the evacuation time is the shortest for single person actions without pairing, followed by the evacuation time for pairing with two people, and the evacuation time is the longest for pairing with three people. As the number of people in groups increases, the evacuation time increases rapidly, indicating that group behavior can affect the efficiency of personnel evacuation during the evacuation process.

This is because during the evacuation process, companionship behavior will encourage members of the team to maintain a close distance. If one member is too far away from other members, the team members may slow down their movement speed and wait or wait in place for outdated personnel to catch up with the team. This not only affects the speed of the team's movement, but also may cause certain congestion, affecting the smooth evacuation of other people around them, thereby increasing the overall evacuation time. Being in a three person group is more likely to experience waiting in place compared to a two person group, because in a two person group, two members are only affected by the distance between each other, but in a three person group, one member is more likely to be affected by the distance between the other two members, triggering deceleration waiting behavior or even waiting in place behavior. Therefore, the evacuation time of a three person group will be higher than that of a two person group.

But in reality, families with elderly people and children always evacuate in groups when facing danger, so the most taboo evacuation method for all three scenarios is to have two people together. If conditions permit, use wider stairs for evacuation as much as possible.

4. EVACUATION PLAN

(1) Evacuation Plan 1: Fire departments in various regions should use Fire Awareness Month, Safety Production Month, Disaster Prevention and Reduction Day, etc. to organize the property management units and owners of high-rise buildings to conduct self inspection of fire hazards and evacuation drills, further enhancing the fire safety awareness and evacuation ability of owners and responsible persons.

(2) Evacuation Plan 2: In terms of high-rise hotel management, elderly and children with lower mobility should be placed on lower floors as much as possible to avoid them being unable to complete safe evacuation in a timely manner due to the long evacuation distance.

(3) Evacuation Plan 3: During safe evacuation, minimize human companionship behavior to the greatest extent possible, and if necessary, reduce the number of companions to avoid crowding caused by companionship behavior, resulting in casualties and property damage.

5. CONCLUSION

High rise hotels have a high density of personnel and complex functions. Once a fire occurs, crowding and trampling incidents are prone to occur during crowd evacuation, often causing serious casualties and property damage. In response to the weak mobility of elderly and children in high-rise hotels, we set up three scenarios and proposed three solutions for each scenario. Using pathfinder software for simulation, we obtained the following conclusions: Research shows that placing elderly and children with low mobility on lower floors can shorten the safe evacuation time and improve the efficiency of safe evacuation; During the process of safe evacuation, companion behavior can affect the efficiency of safe evacuation. Among them, the evacuation efficiency of single person actions without companionship is the fastest, followed by two-person companionship, and the safety evacuation time used by three-person companionship is the longest. We believe that safety education should be carried out for residents, and single person evacuation should be carried out as much as possible during the safe evacuation process. Considering that there are children in the evacuation crowd who cannot be evacuated independently, it is recommended to evacuate with two companions. We do not recommend evacuating with three or more companions; Through research, we further found that as the width of the stairs increases, the evacuation time gradually decreases in each scene.

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