Study on Optimization of Emergency Evacuation Mode of "Multi Source and Multi Sink" In High - Rise Apartments

Feichao Zhang, Bin Xu and Zhuangzhuang Shao

China University of Mining and Technology (Beijing), Beijing, 100083, China

*Corresponding authoremail: 849156072@qq.com, 1192900379@qq.com, 1003882864@qq.com

Abstract. In the emergency evacuation of high-rise apartment, how to quickly and effectively evacuate people has become the focus of attention. In this paper, a college student apartment as the research object, and the evacuation path structure is optimized. The security windows in the first floor are changed into smart switch anti-theft windows, so that each room becomes a temporary evacuation channel, and the "multi source and two sink" is changed into "multi source and multi sink". The model was built using Anylogic software, and the existing evacuation plan and the optimized evacuation plan are simulated and compared. The results show that the evacuation time of the optimized evacuation scheme was reduced from 810s to 375s, evacuation efficiency increased by 53.7%. This paper presents a new structure and program of evacuation of buildings, which can improve the evacuation efficiency in the current situation and provide support for high-level emergency rescue and has the prospect of promotion.

1. Introduction
Safety evacuation of high-rise buildings is a recognized problem in the industry [1]. The British government began the study of building evacuation in the 1930s and proposed that "people should be evacuated in 2.5 minutes in the case of fire" [2]. Khalid put forward the need to provide corresponding matching export quantities for different scale buildings, and emphasized that evacuees should be able to find the most suitable exit for them at the first time [3]. Starting from the crowd safety, corridor safety and export evacuation capacity, Sano found that there is a great relationship between the crowd walking speed and the number of exports in the evacuation channel. It is optimized from two aspects of mobile safety and crowd mobility efficiency [4]. Garcimartin studied the intermittent flow characteristics of evacuees through safety exit and found that there was a constant probability of congestion when the number of safety exit was constant, the number of exit increased and the probability of congestion decreased [5].

At present, there are two aspects of research on high-rise building safety evacuation at home and abroad, the evacuation design of buildings and the evacuation simulation based on pedestrian dynamics [6]. Most previous according to the fire protection design manual, only consider the physical characteristics of the evacuation of buildings, without considering the interaction between flow density and export in the process of evacuation [7-9].
It can be seen that there is a lack of research on evacuation and optimization of scholars from the aspects of high-rise building structure. The problems of limited exit of safety evacuation in the evacuation process and severe traffic congestion have not been solved. According to the characteristics of the first floor of high-rise student apartments often open, this paper proposes an optimization plan for the evacuation structure of existing buildings, that is, under the condition of the emergency evacuation structure of the existing floors, changing each room of the first floor into a temporary evacuation passage and changing the current security exit, less prone to congestion, to achieve emergency evacuation from "multi-source two sinks" to "multi-source more sinks" change. In this paper, we introduce the example of 16-storey dormitory apartment to establish the emergency evacuation model, simulate the evacuation of the model and compare the evacuation time and the degree of evacuation congestion to validate the practical application effect of the optimization.

2. Modeling and simulation of emergency evacuation of apartment

2.1. Optimization of emergency evacuation system
In the process of emergency evacuation of high-rise apartments, the phenomenon of "multiple sources and few sinks" often appears in the flow of occupants, that is, the evacuees are imported from multiple entrances and withdrawn from a few outlets, and the emergent behaviors of occupants in an emergency have great uncertainty, easily in the evacuation passage occurred secondary traffic accidents, which greatly increased the difficulty of emergency evacuation and hazard coefficient. In view of this situation, the existing architectural evacuation structure and evacuation route are optimized by using the idea of "multi source and multi sink". Each room burglar-proof window can be set as the burglar-proof window which can intelligently control the switch. Specifically, the system consists of an alarm, a control room, a smart lock and a security window. In the event of a fire, the alarm will alarm and the central control room will issue an unlock command after receiving the alarm signal. The smart lock will open and the security window can be opened. At this time, each room of first floor together with the anti-theft window that has been opened forms a temporary evacuation channel, Emergency evacuation of the crowd can be close to each room through the open anti-theft window to escape. By setting the original locked anti-theft window to a smart anti-theft window that can be opened automatically, all the rooms on the ground floor will be temporarily evacuated to realize the transition from "Multi-source and Dual-sink" to "Multi-source and Multi-sink", can improve the evacuation speed, reduce the degree of congestion evacuation process.

2.2. Construction of apartment evacuation model
In this study, a college student apartment as a simulation object, the apartment was inverted font, a total of 16 floors on the ground, belonging to high-rise buildings; the ground floor plan of the apartment is shown in Figure 1, with a total of 48 dormitories on each floor and 6 students in each dormitory. The total number of apartments is about 4,608; there are altogether 4 staircases in the apartment, which are stairs 1 to 4 respectively. The evacuation route is divided into three zones, namely I, II and III. According to Figure 1, the emergency evacuation geometry model is established, and the Anylogic software is used to simulate the model. The software can change the equation of the staff flow state in the model with different building structures in the model, and can accurately simulate the states under the flow of occupants, so continuous process can drive discrete logic [10, 11].
2.3. Design of simulation parameters for emergency evacuation

In the process of emergency evacuation, the speed of emergency decision-making and evacuation is quite different from that under normal conditions. Therefore, according to the past empirical formula and observation record, the emergency decision-making and speed parameters in the model are determined.

2.3.1. Emergency decision-making

The model simulates a fire at 12:00 at night in the apartment and needs an emergency evacuation. According to the analysis of the previous observation records, the elevator was disabled in the event of a fire and 4,320 students in the 2-16 floors will be evacuated to the ground floor with 4 flights of stairs and each of them will be evacuated about 1,080 people.

In the current evacuation program, these students had the only evacuation route, which was to reach exit 1 and exit 2 through Regions I, II and III in sequence; After the optimization of the structure of "multi source and multi sink", these students can not only evacuate through Exit 1 and Exit 2, but also evacuate to safe places through windows in dormitories of one floor.

2.3.2. Velocity parameters

During the first stage, there will be a cluster effect after people converge to the stairs. For simplicity, the evacuation channel population as a whole, the flow contains a certain number of occupants, occupants with a certain density, different people have different popular walking speed density. Some scholars at home and abroad have observed and studied this cluster evacuation and given a number of fitting relationships of abortion. Eq.1 [12]:

\[ u = 112p^4 - 380p^3 + 434p^2 - 217p + 57 \left( \frac{m}{min} \right) \]  

Where: \( u \) said the flow of people in the stairs evacuation speed, m / s; 
\( p \) represents the projected area of the population per unit area (m / m²), generally (0 <p <0.9); 
Consider the impact of a small space, the general to give an impact coefficient, namely:

\[ v_c = uc \]  

For the staircase:

\[ c = 0.775 + 0.44e^{-0.299} \sin(5.16p - 0.224) \]  

From the above analysis, it is determined that the flow rate at the exit of the staircase is 8 persons per second.
In the second stage, the evacuation process is handled as each individual population. Taking into account the evacuation characteristics of each evacuee such as location, speed and direction of evacuation, the individual evacuation occupants characteristics must also be considered for the speed calculation formula, so the selection Eq.2 to calculate [13].

\[
v_j = (p_1, p_2) = v_j(p) = v_{in}(\alpha A + \beta B + \gamma)
\]

\[
A = 0.81 - 0.93\ln(p)
B = 4.0 - 1.89p
\]

Where: \(v_j\) said the number of individual evacuation speed \(j\), \(m/s\);
\(\alpha\) and \(\beta\) represent the influencing factors of the progress of the people when they are crowded. According to the practical data, \(\alpha = 0.42\) and \(\beta = 0.027\), respectively;
\(\gamma\) as a personal physical characteristics of the impact factors, are generally divided into normal adults, the elderly and disabled people, where normal 0.24;
\(v_{in}\) Plane moving speed, as 1.2 ~ 1.8m/s.

The velocity parameters of the evacuation crowd in the above two stages are brought into the simulation system for calculation, and the time required for evacuation of the whole population can be obtained.

2.4. Simulation of the operation
This model mainly simulates the evacuation of occupants in the evacuation channel of the first floor. Through the simulation, the evacuation situation under the two schemes is obtained. Figure 2 shows the evacuation at half time when the existing evacuation plan is adopted, i.e. 400s. Figure 3 shows the evacuation at half time after the optimization of multi-source and multi-sink structure, i.e. 150s.

![Figure 2](image1.png)
![Figure 3](image2.png)

**Figure 2.** Evacuation of “multi-source two sinks ” evacuation structure 400s
**Figure 3.** Evacuation of “multi source and multi sink” evacuation structure 150s

Small dots in the picture indicate individuals who are evacuated. The degree of density of small dots indicates the degree of density of people. As can be seen from the comparison of the two figures, the number of small dots in Figure 2 is obviously higher than that in Figure 3, and the aggregation features of individual areas are presented.

3. Comparison and analysis of simulation results of emergency evacuation
The shortest evacuation time, the least congestion and the shortest total evacuation route are three important indicators of emergency evacuation, which can objectively reflect the emergency evacuation capacity of a high-rise building [14]. The following three aspects of the optimization analysis will be carried out.
3.1. Evacuation time analysis

When a fire occurs in a building, the time a person can evacuate to a safe place is to allow evacuation time. For high-rise buildings, refers to the time to reach the enclosed stairwell, anti-smoking stairwell, refuge layer, which allows evacuation time of 5 ~ 7min.

Occupants’ safety evacuation time is composed of three parts: detection alarm time $T_d$, preparation time $T_r$ and movement time $T_t$. The time spent from the occurrence of a fire to the alarm or the evacuation conducted by the staff to spread the disaster is called the alarm time $T_d$. The time the crowd experienced from the discovery of danger to the beginning of evacuation is called the preparation time $T_r$. The time of complete evacuation is called movement time $T_t$ [15].

Therefore, the total time required to evacuate occupants during a fire is:

$$T_{\text{total}}=T_d+T_r+T_t$$ (5)

Where: $T_d$ - alarm time, s; $T_r$ - preparation time, s; $T_t$ - movement time, s.

After optimization of the structure of "multi-source and multi-sink", the evacuation exit increases and the occupants's movement time from the staircase to the safe exit will change. That is, $T_t$ will change while $T_d$ and $T_r$ will not change. Therefore, program evacuation time difference is the change of $T_t$.

Under the existing evacuation plan, 810S (12.5min) is shared when the evacuation is shared, and the national standard of "5-7min evacuation" is not reached [16]; after the optimization of "multi-source and multi-sink" structure, the occupants evacuation simulation takes 375s (about 6.3min) to reach the Chinese national standard of "evacuation within 5-7min."

It can be seen from the comparison that after the optimization, the evacuation time is reduced from 810s to 375s, the evacuation speed is obviously accelerated and evacuation efficiency is improved by 53.7%. Visible, from "multi-source two sinks" structure into the "multi-source multi-sink" structure significantly speed up the evacuation rate and enhance evacuation efficiency.

3.2. Analysis of evacuation congestion

In the event of a fire, all of them are highly strained toward the evacuation exit and are prone to overcrowding in the limited space of evacuation routes. The following analysis is conducted on the degree of evacuation and congestion.

3.2.1. Analysis of evacuation density map In order to compare the population density of the evacuation route under the two evacuation schemes, we obtain the pedestrian density map under the two schemes, as shown in Figure 4 and Figure 5.

![Figure 4. Evacuation density map of “multi source and two sink “evacuation structure 400s](image-url)
Figure 5. Pedestrian density map for evacuation of "multi source and multi sink" evacuation structure 150s

Figure color depth indicates the size of occupants density, on the whole, Figure 5 is lighter than the color of Figure 4, which means that the density of pedestrians is small; Specifically, the contrast between the two maps shows that there is not much difference in color in area I, and the difference between the two is mainly shown in areas II and III, that is to say, from the entire process of evacuation occupants evacuating from the stairway to the safety exit, the optimized flow density is lower than that of the existing situation of crowd density.

As can be seen from the comparison of Figure 4 and Figure 5, after the optimization of "multi-source and multi-sinks", the pedestrian density in the process of evacuation of occupants is significantly reduced, indicating that it is practical and effective to change each room into a temporary evacuation channel, which can effectively reduce the evacuation process pedestrian density, so as to avoid all rushed to safety exit and the occurrence of the stampede accident.

3.2.2. Analysis of human flow line chart the density distribution of people flow evacuation reflects the maximum population density during the entire evacuation process and does not reflect the population density at each time point in the major congested areas. Therefore, the line chart of the population flow in the key congested areas can be drawn to reflect the real-time human traffic in the area. From Figure 4 and Figure 5, we can see that in the evacuation process, the density of people flow is the largest in area II of Figure 4 and the area I of Figure 5. Therefore, in order to make the statistical data representative, we choose region A and region B as the statistical regions with the highest population density in area II and area I, as shown in Figure 6.
By calculating the real-time traffic in the two regions in the process of evacuation, we can get the fold chart of the entire flow of evacuation in the two regions, as shown in Figure 7 and Figure 8.

**Figure 6.** Ground floor plan

**Figure 7.** Real time flow chart of human flow in an area of "multi source two sink" evacuation structure

**Figure 8.** Real time flow chart of human flow in B area of "multi source and multi sink" evacuation structure

**Figure 9.** The total number of evacuations in each window during the evacuation process
Figure 7 and Figure 8 show the human flow chart of the A and B regions during the evacuation process. It can be seen from Figure 7 that in the A region, the flow of people first increases to the peak within about 0-100s, about 120, and then begins to decline. The flow of people gradually stabilizes at 60 and the flow of people begins to decline from 750s. The flow of 810s becomes 0; As you can see from Figure 8, the human flow in the B region increases first to the peak in the 0~100s area, about 70 people, and then in the 100~380s period, the human flow continues to decrease until 0. From the comparative analysis of Figure 7 and Figure 8, the peak and mean values of human traffic in the A area are larger than those in B area. After optimization, the maximum flow density is reduced from 120 people in the unit area to 70 people, and the average traffic volume is reduced from 70 to 30. These figures can indicate that "multi source and two sink" is optimized to be "multi source and multi sink", which helps to reduce the density of pedestrian flow and reduce the degree of congestion, so as to avoid accidents such as stampede in evacuation process.

3.3. Analysis of the correlation between the shortest evacuation route and the minimum congestion level

In order to better find the relationship between the shortest evacuation route and the lowest degree of congestion, a total number of evacuation maps of each window in the evacuation process is drawn. Because the model has the right and left symmetry, the number of evacuations in the left window is counted only. As shown in Figure 6, the windows on the left side of the plan view are marked with numbers ①～⑪sequentially to count the number of people evacuated from each window during the evacuation process, and the broken line chart is drawn as shown in Figure 9.

The 1st and 3rd stairs correspond to the positions of 10 windows and 1 window respectively. From Figure 7, the distances from 1 to 6 windows to the stairs 3 are gradually increased, and the number of people evacuated gradually decreases. The number of 10~6 windows increased gradually from No. 1 staircase, and the number of evacuations was gradually reduced. Therefore, the tendency of the line chart can be concluded that in the corresponding range, the farther away from the exit of the stairs, the fewer the evacuation occupants, indicating that the evacuation route length and the number of evacuation was inversely proportional relationship.

4. Conclusion

In this paper, a college student apartment as the research object, the existing evacuation path structure optimization program design. With reference to the high-rise apartment building simulation model, the existing evacuation plan and the optimized evacuation plan are simulated and compared, and the following conclusions are drawn:

(1) The dormitory anti-theft windows in the first floor can be changed into an intelligent burglar proof window, so that each room can be changed into a temporary evacuation channel. The optimization plan of "multi source and two sinks" for "multi source and multi sink" can improve the efficiency of high-rise evacuation.

(2) After the evacuation structure was optimized, the evacuation time of the optimized evacuation program was reduced from 810s to 375s, evacuation efficiency increased by 53.7%.

(3) The evacuees instinctively sought to escape from their nearest exit and the "multi-source and multi-sink" optimization scheme could take advantage of its multiple exit to avoid crowding caused by the evacuation of people to the same exit during the evacuation process.

In this paper, a new optimization plan of building evacuation structure, based on the existing building evacuation facilities, can be slightly modified based on the evacuation capability of emergency evacuation of high-rise buildings, which has the characteristics of simple solution and easy implementation, and has certain promotion prospect.
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