Simulation and Optimization of Emergency Evacuation of Huoshenshan Hospital Based on BIM and Pathfinder

Liujia Wang, Zishu Xiang, Yaxing Chen, Dalin Li and Jian Wang*

School of Urban Construction, Wuhan University of Science and Technology, Wuhan, China

Abstract. After the outbreak of the Covid-19 epidemic, Huoshenshan Hospital, as the main place for patient isolation, is characterized by large floor space and high staff density, and its evacuation time is directly related to the safety of patients and medical care. In this article, we use BIM and Pathfinder software to establish an emergency evacuation simulation model, setting 2400 patients of different ages and degrees to participate in the simulation, and carry out the simulation in Steering behavior mode to study the influence of evacuation mode, exit size and initial distribution of personnel on the evacuation time and evacuation distance of Huoshenshan Hospital respectively. The simulation results provide a theoretical basis for the standardized management of Huoshenshan Hospital and have certain reference significance.

1. Introduction

Since the outbreak of the Covid-19 epidemic, China's guiding philosophy of "detect as much as possible and collect as much as possible" has been recognized by most countries in the world, and China's experience has become the world's first proven experience in fighting the epidemic. Although the Covid-19 vaccine has been introduced widely, the effectiveness of protection has yet to be proven. In the absence of a specific drug, the most effective way to stop the spread of the virus was isolation, and the establishment of the Huoshenshan Hospital, the Leishenshan Hospital, and the Wuhan Living Room and other mobile cabin hospitals set a model for the world. Although the epidemic has been effectively controlled in China, the pressure to " defending externally against importation, defending internally against rebound " is still tremendous, and the rebound of the epidemic in Suifenhe and Shulan is a warning bell. In the next year or two, epidemic prevention will become normalized, and with the general trend of building mobile cabin hospitals everywhere, it is necessary to study the emergency evacuation plan for mobile cabin hospitals.

Various pieces of simulation software are used internationally to simulate the evacuation process in various situations, such as STEPS, Simulex, BulidingEXODUS, Pathfinder, etc. Among them, STEPS, Simulex, BulidingEXODUS is a rough network model, and Pathfinder is a continuous model[1]. Pathfinder is a new intelligent emergency evacuation and escape assessment system developed by Thunderhead Engineering, which uses computer graphics simulation and technology in the field of game characters to perform a graphical virtual rehearsal of each individual movement in multiple groups so that each individual can accurately determine the rapid escape path in the event of a disaster and escape time[2-5]. The software includes two modes, SFPE and Steering, in which people keep a certain distance from each other and choose the exit according to the number of people, while Steering mode uses path planning, collision processing and guidance mechanisms to handle the movement of evacuees, which is closer to the real scenario of evacuation[6].

2. BIM model building

According to public information: The height of Huoshenshan Hospital is 2.5m, with a total construction area of 33,900 square meters and 1,000 beds, including waiting areas, general wards, ICU rooms, operating rooms, toilets, operation rooms, protective clothing rooms, consumables warehouses and so on. These paper models Huoshenshan Hospital using Revit 2016 software.The building is only one floor, with a height of 2.5m. It does not need to be set up the stairs. Except for some special passageways, the main dimensions of the building doors are 1600 * 2100 (double doors) and 900 * 2100 (single door).

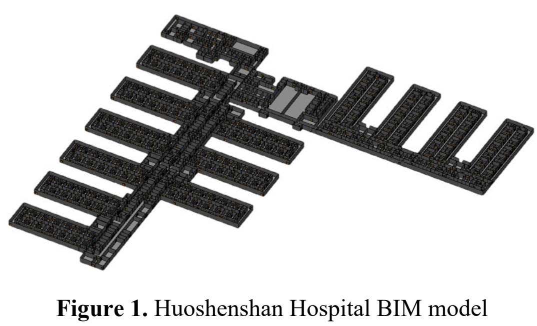

Figure 1. Huoshenshan Hospital BIM model

* Corresponding author: okwj@wust.edu.cn

3. Pathfinder evacuation simulation

3.1 Personnel basic parameter setting

The basic personnel parameters in the Pathfinder software mainly include Shoulder width, height, and evacuation speed setting. The accurate setting of shoulder width can make the evacuation results closer to the escape situation in a real fire situation. It is based on the New National Standard of Human Dimensions of Chinese Adults (GB / T10000-1988) and the New National Standard of Human Dimensions of Chinese Minors (GB / T26158-2010) that is released by the State Administration of Technical Supervision. According to the follow-up survey and research data, the mean values of human parameters of minors, young women, middle-aged women, young men, middle-aged men and the elderly were selected and set. The age and sex ratio of the patients were determined according to the paper published by Academician Zhong Nanshan and the 37 national frontline authors on the medRxiv preprint website on February 9th. The paper included the information of 1,099 COVID-19 patients in 552 hospitals in 31 provinces or municipalities across the country. According to the public information, Huoshenshan Hospital has a total of 1,000 beds, about 1,400 medical staff. Ordinary patients and medical staff are evacuated at a similar evacuation rate. Severe patients due to breathing difficulties and systemic fatigue, the evacuation rate is designed according to 50% of the normal speed. The final selected personnel parameters are shown in Table 1. There are 2400 people with medical staff and patients.

Table 1. Personnel basic parameter setting

age group		shoulder breadth (cm)	height (m)	number of people	Evacuation speed(m/s)
juveniles	ordinary	30.3	1.35	8	0.75
	Severe case			1	0.375
young women	ordinary	37.2	1.66	194	1.02
	Severe case			36	0.51
middle-aged women	ordinary	37.2	1.63	102	1.00
	Severe case			19	0.5
middle-aged women	ordinary	40.4	1.75	270	1.20
	Severe case			51	0.6
middle-aged men	ordinary	40.1	1.70	142	1.10
	Severe case			26	0.55
old people	ordinary	36.1	1.61	127	0.60
	Severe case			24	0.3
male nurse		40.4	1.75	700	1.20
female nurse		37.2	1.66	700	1.02

3.2 Simulation working condition design

According to public information, Huoshenshan Hospital includes waiting areas, general wards, ICU rooms, operating rooms, toilets, operation rooms, protective clothing rooms, consumables warehouses and so on. To facilitate the distribution of personnel, this paper divides the building into 4 work areas, 13 ward areas, and an ICU room.

3.2.1 Influence of patient evacuation mode

The simulation process was divided into working condition 1 self-evacuation and working condition 2 assisted evacuation. In self-evacuation, although the mobility of critically ill patients is reduced by half, they can evacuate by wheelchair on their own. When critically ill patients do not have the ability to move freely, they need the assistance of medical staff to evacuate. As the number of medical personnel is much larger than that of the critically ill patients and are all distributed in the whole model, in order to reduce the impact of the stay time of medical personnel in the process of searching for the critically ill patients on the whole evacuation time, 50% of the medical personnel are set to assist the critically ill patients to evacuate, and the remaining medical personnel and ordinary patients evacuate by themselves.

3.2.2 Influence of exit size

According to the simulation results under different evacuation methods, analyze the personnel density of the exit during the evacuation process, select the exit with greater influence on the simulation results, increase the exit size and set it as a working condition.

3.2.3 Influence of initial position of personnel

Working condition 4 reduces the evacuation time by adjusting the initial position of the personnel, and distributes the medical personnel evenly throughout the model, with the critically ill patients evenly in the ICU room and the ward area near the exit, and the general patients in other ward areas.

4. Results and analysis

4.1 Influence of patient evacuation mode

In the first working condition, among 2400 people, the maximum time consumed is 218.2s, the minimum time consumed is 5.1s, the average time consumed is 55.9s, the maximum moving distance is 127.7m, the minimum moving distance is 5.5m, the average moving distance is 41.7m. In the second working condition, among 2400 people, the maximum time consumed is 233.1s, the minimum time consumed is 5.6s, the average time consumed is 61.9s, the maximum moving distance is 114m, the minimum moving distance is 6.7m. It can be seen that the average elapsed time increased by 10.73% when considering the case of assisting critically ill patients, and the average distance increased by only 3.12% because the distribution of personnel remained basically the same.

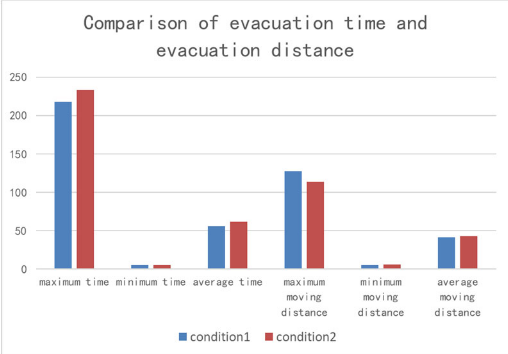

Figure 2. Comparison of evacuation time and evacuation distance under working conditions 1 and 2

There are 13 rooms and corridors with more than 30 evacuees in total, which are mainly concentrated in the periphery of the building and the public corridor of the partition, but there are only two emergency exits, resulting in the reduction of evacuation speed and the increase of evacuation time.

It can be inferred from the 40-second personnel density distribution map that the positions with the highest personnel density are at the gate outside the hospital, which has reached 3 people per square meter. The door with the largest number of evacuees is shown in the figure. The average evacuation speed of gate 1 is only 0.55 people per second.

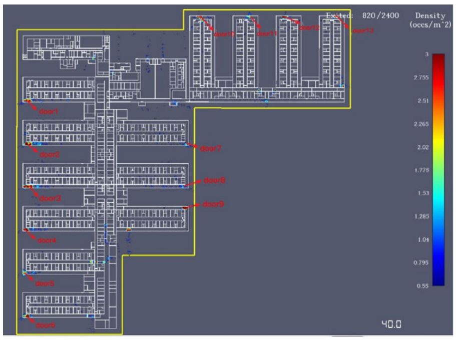

Figure 3. Working condition 2. Intensive outlet distribution

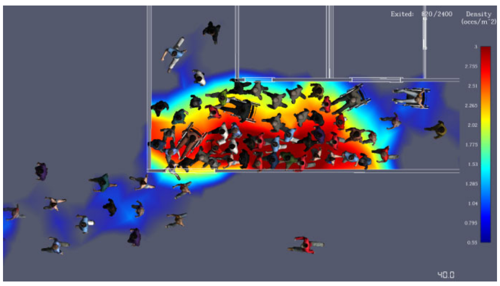

Figure 4. For a single-gate-1 density distribution

4.2 Influence of outlet size

The most crowded exit locations are doors 1 to 13 in every ward, in order to improve the evacuation speed, the size of doors 1 to 13 was increased to 2.6m, so it can be set as condition 3. The calculation results of the increased exits are as follows.

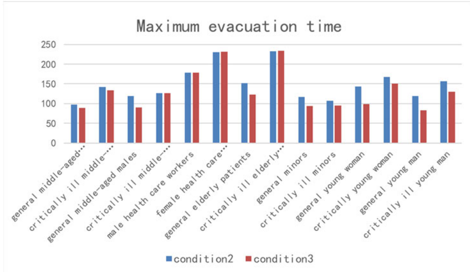

Figure 5. Comparison of maximum evacuation time in working condition 2 and 3

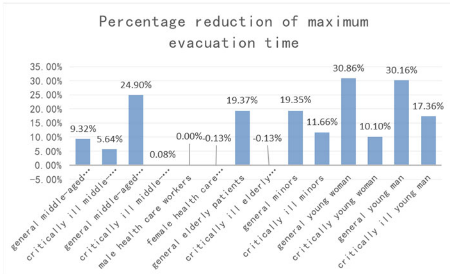

Figure 6. Maximum evacuation time percentage reduction in working condition 3

It can be seen from the statistical data that the increase in exit size has a certain impact on the reduction of evacuation time. The total evacuation time is 233.4s, among which middle-aged men, young men, young women, and the elderly have the largest percentage reduction in evacuation time, reaching 24.90%, 30.16%, 30.86%, and 19.37% respectively, while the population with the smallest percentage reduction in evacuation time is mainly concentrated in severe patients For nurses who need to assist critical patients and elderly people who move slowly, the evacuation time of critical middle-aged women, critical middle-aged men, male medical staff, female medical staff, and critical elderly only decreased by 5.64%, 0.08%, 0.00%, - 0.13%, and - 0.13%. The longest evacuation time was for a critical elderly person.

It can be seen that in order to further improve the evacuation efficiency, the solution of only increasing the outlet size cannot further improve the evacuation efficiency. In fact, from the graph of the cumulative number of evacuees at the exit, it can be seen that at about 120s, the number of evacuees has reached 2366, which is about 96.92% of the total. The size of the exit is no longer a limiting factor for the evacuation time. To continue to improve evacuation time, it is necessary to increase the speed of slower-moving people or reduce their evacuation distance.

4.3 Impact of initial position of personnel

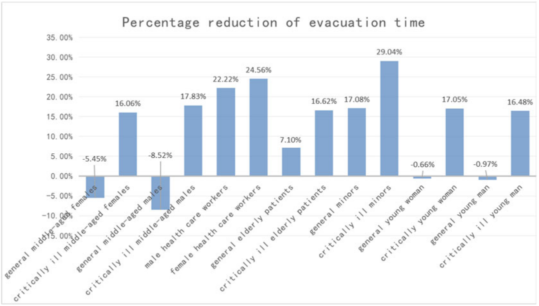

Figure 7. Percentage reduction of average evacuation time under Condition 4

Considering the actual situation, it is difficult to improve the movement speed, but it is practical to shorten the evacuation distance, that is, to adjust the slow-moving crowd to the position close to the emergency exit. The critical patients were moved to the room close to the emergency exit and set as condition 4. The total evacuation time was shortened to 160s, saving about 30% compared with that before optimization. Due to the readjustment of personnel positions, the comparison of the maximum evacuation time of the classified population is not very significant. The average evacuation time of all kinds of personnel is more uniform. For the evacuation distance, except for the evacuation time of general patients, the evacuation time of other critically ill patients and medical staff is significantly reduced, especially for elderly patients with severe diseases, the average evacuation time is reduced from 133.6s to 111.4s, greatly reducing the total evacuation time.

5. Conclusions

This paper studies the impact of evacuation mode, exit size and initial distribution of personnel on emergency evacuation and the following conclusions can be drawn:
(1) When considering assisting critically ill patients, the time taken is significantly higher than self-evacuation. In the actual simulation process, the situation that critically ill patients need assistance cannot be ignored.
(2) Increasing the size of the exit can effectively alleviate the congestion of people, and the maximum evacuation time of different groups has also been significantly reduced, but the impact on the total evacuation time is small.
(3) When the critically ill patients are arranged to the ward close to the exit, the simulated evacuation time is significantly reduced by about 30%. Without changing the existing building structure, the optimization effect can be achieved by adjusting the personnel distribution, thus significantly reducing the evacuation time.

Acknowledgments

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