Study on Emergency Evacuation Simulation and Strategy of Old Dormitory Building in College- A Case Study in China

Yan Li and Yan Zhang
School of Management, Xi'an University of Science & Technology, Xi'an, China
Email: 632058171@qq.com, 827191798@qq.com

JianPing Jiang
School of Construction and Safety Engineering, Shanghai Institute of Technology, Shanghai, China
Email: 2878529499@qq.ccom

***Abstract*—In order to study the emergency evacuation effect of old dormitory buildings in colleges and universities, an old dormitory building of a large university is taken as an example, the Pathfinder software platform is used to set parameters of the building and occupants, and many evacuation simulations of the university dormitory building are carried out. Six different scenes are simulated through designing and adjusting pre-evacuation time, safe exit setting and occupant distribution. The results show that pre-evacuation time, safe exit setting and occupant distribution will have a significant impact on the total evacuation time. Finally, it is concluded that the administrator center of college dormitory should strengthen the management of security export settings of dormitories and ensure that all safe exits are opened and strengthen the emergency drill and train for dormitory residents. And reasonable occupant distribution should be taken seriously in order to improve the emergency evacuation efficiency of the old dormitory buildings in colleges effectively. The specific theoretical and practical implications will also lead emergency administrators to pay more attention to security settings and management behavior in order to improve evacuation efficiency.**

***Index Terms*—old dormitory building, personnel evacuation, Pathfinder, evacuation simulation, emergency management**

I. Introduction

Nowadays, a growing number students are entering university with the popularity of education, so, the demand for dormitories or university residential buildings is increasing. However, there are many old dormitories with defects in safety facilities and emergency evacuation, which lead to the dormitory itself cannot cope with the disaster in the event of an emergency. In addition, many incidents of campus attacks and natural disasters have happened frequently in recent years, which have caused great loss and harm to students and teachers. And improper evacuations would cause serious secondary injuries, such as stampedes and injuries, when these emergencies occur [1]. This would cause greater damage and loss. Therefore, it is very important to strengthen the emergency management of old dormitory buildings in order to reduce the harm and loss caused by the emergency, and then to ensure that all occupants are evacuated to safe areas safely and quickly when an emergency occurs [2].

Many countries have become aware of the significance of emergency evacuation and increasing researchers have used different evacuation models to simulate various evacuation processes since the 20th century. The evacuation process of different dormitories and university residential buildings and the behavior and mental state of occupants are studied in detail with these methods of Network model [3, 4], Cellular automata model [5], Agent-Based Modeling (ABM) and Geographic Information System (GIS) [6], Social Force Model [7], Closed circuit TV system [8], Qualitative Character Study Model [9] and Control volume model [10], and so on.

AysuSagun et al. [11] studied the connection between building design problems and safe evacuation. In addition, field observation and case simulation were used to study the export preference of residents in the building during emergency evacuation. Furthermore, it is suggested that the unbalanced use of safe exits in buildings will increase the evacuation time and reduce the evacuation effect. Claridades, Alexis Richard C. et al. [6] used the ABM and the GIS to build a three-dimensional Geographic Information System model for the dormitory building according to the plan and population data of the dormitory building. The study showed that the state of occupants and the width of evacuation path had a certain effect on the evacuation time during emergency evacuation. Ronchi Email et al. [3] used a sophisticated Network model to simulate two strategies for using stairs or elevators to evacuate crew during the evacuation in a high-rise buildings, which showed that the efficiency of these evacuation strategies would be reduced

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significantly if there is no proper information transmission to guide the behavior of occupants in high-rise buildings. Lei, Wenjun et al. [12] showed that the average minimum width of corridors and exits were the two key parameters affecting the evacuation of dormitory. And the FDS Evac software was applied to simulate a dormitory building in a university in order to verify that the evacuation time was not related to the evacuation distance. In addition, they proposed that the optimal width of corridor in the dormitory building was 3m, and the optimal width of emergency exit was 2.5m to 3m. And the number of occupants had a certain effect on the evacuation efficiency. Ma Zichao et al. [13] focused on the impact of fire accidents on evacuation, the PyroSim+ Pathfinder software platform is used to build a fire and evacuation simulation model for a university residential building, and they suggested that adding the hanging stairs could improve the evacuation efficiency during emergency evacuation.

To sum up, many scholars have studied the emergency evacuation of dormitory buildings in detail. However, most studies were related to the internal design of the dormitory building and the research on the emergency evacuation management of the dormitory building was lacking. Therefore, an old dormitory building of a large university is taken as an example and the Pathfinder software platform is used to study the emergency evacuation of old dormitories in college, in order to provide the theoretical and practical basis for the emergency evacuation management of old dormitory buildings in universities.

II. Simulation Model and Architectural Description

A. Pathfinder Simulation Model

The Pathfinder is a simulator based on people's access and movement. And it was developed by Thunderhead engineering in the United States. This section briefly describes some key features of Pathfinder model for reader’s convenience. More detailed description on Pathfinder and its model and data validation can be found in [14]. In order to simulate design and the execution, Pathfinder simulation model provides users with an interface which can build and run simulation models and show the simulation results of 3D visualization [15]. The software includes a three-dimensional grid model that can simulate the evacuation process of all residents during normal or emergency situations. Its grid decomposition can speed up the operation. Therefore, it is suitable for various buildings to conduct safety assessment. And its visibility is so strong that it can clearly see the evacuation dynamic process of each time and record the evacuation data in detail [16]. In addition, Pathfinder also provides two-dimensional, temporal-oriented graphical CSV files and texts that summarize the floor evacuation time and the flow rate of entries and exits. By setting parameters of occupants including shoulder width, walking speed, etc., residents will automatically select the best evacuation path according to the change of the evacuation environment [17]. Several features to determine the final evacuation data are defined as follows:

Walls and other blocked areas are represented as intervals in the navigation grid. These objects do not really pass to the emulator, but they are denoted implicitly. This because residents cannot move without a navigation grid.

The door is represented as the edge of a special navigation grid. In all simulations, the door provides a way to connecting the room and tracking the flow of occupants. Depending on the simulation options, the door can also be used to control the flow of occupants explicitly.

The staircase is also represented as boundary and triangular form in a special navigation grid. The occupants move at a slower rate since the horizontal walking speed is based on the slope of the stairs. Each staircase has two doors that have the same functions with any other door in the simulation but are edited by the staircase that controls the user interface, which ensures that there is no geometric error resulting from the mismatch between the staircase and the connection door. Residents are modeled as an upright cylinder and a technique based on subject is used when they walk in the motion grid. Each occupant’s independent movement can be calculated and a set of unique parameters (the top speed, exit options, etc.) are given.

Pathfinder model supports two types of motion simulation, i.e. SFPE mode and steering mode. In SFPE mode, the pedestrian walking will not interfere with each other, and there will not happen jam phenomenon. The occupant’s speed is affected by the space density of room, and traffic flow at the exit is set according to the exit width. In the mode of steering, the flow of crowd will not be restricted by the door. Instead, the system can be manipulated to keep crowd at a reasonable distance. Users can switch these modes and compare the simulation results freely [18]. Considering the behavior of residents in the emergency situations and the possible congestion situation, this paper adopts the mode of steering.

B. Simulated Building

In order to address our research issues, we apply the simulation model to a building and study the evacuation process with various setting of the building environment. This building is a 6-story dormitory building located in Xi’an City, Shaanxi Province, China and the length of the building is estimated to be about 45m and the width is about 12m and the height is about 18m. The dormitory building is old and low relatively, and it is independent of other buildings, and the characteristics of it are representative. The building is counted to be 6 floors and 144 rooms. And each floor is counted to be 24 rooms and two washing rooms, each room can accommodate 8 people. And the length of one room is estimated to be about 5m, the width is about 3m and the height is about 3m. It have clear passages for occupants to reach the exit door and there is no any potential of the room being overly furnished that would hinder evacuation each stair has a total of 10 steps with a tread of 30 cm and a riser height of 15 cm and the other dimensions of the stairs are shown in Fig. 1. As well as two safe exits connected with stairs are setting in the first floor. And the width of each exit is 3m which is in line with the best safety export requirements [12]. However, only the exit of the east stairway is opened and the exit of the western stairway has been closed usually. We graphically present a common floor layout for all floors in Fig. 2.

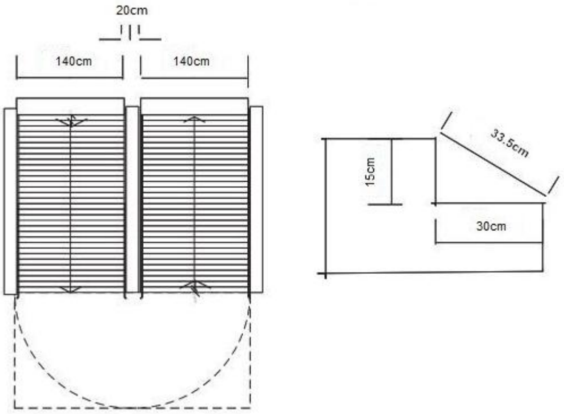

Figure 1. Dimensions of the stairs.

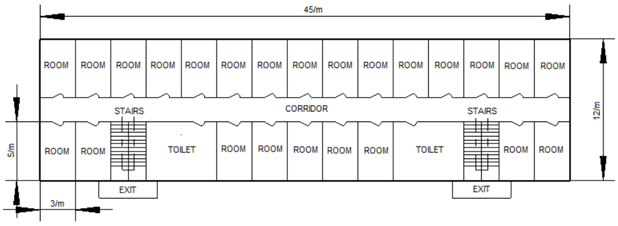

Figure 2. The plan of dormitory building (m).

According to on-the-spot observation, the sleep period after 11:00 PM every night has the biggest turnover in the dormitory. But all residents can only evacuate from the east exit. In the light of the accommodation arrangement of the university, we conduct field survey and calculate the status and number of residents. It is learned that residents of the dormitory is mixed with the male-to-female ratio was is 1:3. The male PhD students live in the first floor and the second floors and two dormitory administrators live in the first floor; the female PhD students live in the third and the forth floor; the female postgraduates live in the fifth and the sixth floor. The concrete occupant distribution is shown as Table I.

TABLE I. THE NUMBER OF PEOPLE ON EACH FLOOR IN DORMITORY BUILDING (PER)

Floor	Floor1	Floor2	Floor3	Floor4	Floor5	Floor6	Total
Number	95	90	96	94	192	192	759

III. SIMULATION PROCESS ANALYSIS

1) Residents on each floor are distributed randomly;

2) Residents choose the shortest path to escape by default;

3) Residents choose the east and the west exit to undertake evacuation in each floor;

4) The alarming response is not considered.

The shoulder width of the adult male is set to 0.415m, the speed is set to 1.19m/s; the shoulder width of adult female is set to 0.378m, and the speed is set to 0.9m/s on the basis of Human Dimensions of Chinese Adults GB10000-88 [19].

A. The Effect of Pre-evacuation Time on Evacuation Performance

The total evacuation time mainly includes pre-evacuation time and evacuation time on the channel in buildings. In order to simulate the evacuation situation of dormitory buildings more accurately, the effect of pre-evacuation time on evacuation performance is analyzed firstly. Then it provides the theoretical basis for setting up the pre-evacuation time for further simulation.

Scene setting: The lower limit of pre-evacuation time is 0s, the upper limit starts from 0s, adding one with each 30s, and the maximum value is 300s.Three series (759 occupants, 639 occupants, 399 occupants) are set according to the occupant load, and there are 11 scenes of each series. So there are 33 evacuation scenes as shown in Table II.

TABLE II. EVACUATION SCENES AND RESULTS OF DIFFERENT PRE-EVACUATION TIME

Scene numbering	Pre-evacuation time(per)	Occupant load(per)	Total evacuation time(s)
2AA	0	759	229.5
2AB	0-30	759	230.8
2AC	0-60	759	234.5
2AD	0-90	759	240.8
2AE	0-120	759	257.3
2AF	0-150	759	265.5
2AG	0-180	759	267.6
2AH	0-210	759	268.8
2AI	0-240	759	297.3
2AJ	0-270	759	326.3
2AK	0-300	759	355.5
2BA	0	639	194.5
2BB	0-30	639	208.3
2BC	0-60	639	214.8
2BD	0-90	639	226.5
2BE	0-120	639	237.8
2BF	0-150	639	245
2BG	0-180	639	254.3
2BH	0-210	639	270.8
2BI	0-240	639	300.3
2BJ	0-270	639	330
2BK	0-300	639	359.5
2CA	0	399	136
2CB	0-30	399	151
2CC	0-60	399	166.5
2CD	0-90	399	174.3
2CE	0-120	399	186.8
2CF	0-150	399	211.5
2CG	0-180	399	241.5
2CH	0-210	399	271.5
2CI	0-240	399	301.3
2CJ	0-270	399	331.3
2CK	0-300	399	361

According to the data in Table II, with the pre-evacuation time as the abscissa and the total evacuation time of three series of 2A, 2B and 2C as the ordinate, the variation trend of total evacuation time with pre-evacuation time is shown in Fig. 3.

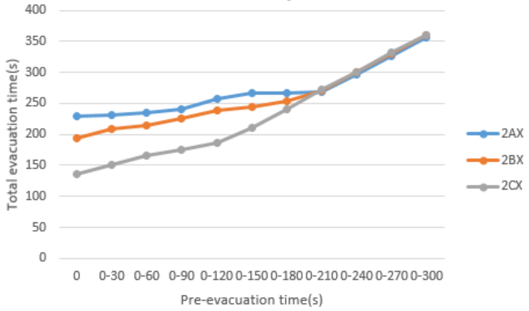

Figure 3. The effect of reaction time on total evacuation time

It can be seen from Fig. 3 that the total evacuation time increases with the increase of pre-evacuation time gradually. The growth curve can be divided into three stages. In the first stage, the growth trend is not obvious, and the reaction time has no effect on the total evacuation time basically; the second part is the accelerated growth stage, and the effect of pre-evacuation time is strengthened gradually; the third stage is the stable growth stage, and the increase of total evacuation time depends on the increase of reaction time entirely.

The comparison and analysis of the three series shows that the total evacuation time of 2AX is up to twice the total time of 2CX, which illustrates that the influence of occupant load on the total evacuation time is very large and the pre-evacuation time has little effect on the total evacuation time when the pre-evacuation time is short; But the three curves are coincident basically when the pre-evacuation time is over 210s, which shows that the effect of load factor on total evacuation time is negligible and the total evacuation time will be increase and the evacuation efficiency will be reduced greatly when the pre-evacuation time is too long.

There are 759 occupants living in the dormitory, and in view of the influence of the status, age and sex of occupants on pre-evacuation time, a survey is conducted on the residence of the dormitory. It is concluded that almost all people can respond within 60s when an emergency occurs. Moreover, the above analysis shows that the pre-evacuation time has no effect on the total evacuation time when the reaction time is within the 90s. Therefore, the pre-evacuation time is set to 0-60s in the following simulation.

B. Simulation Scenario Design

This section mainly conducts the following comparison simulation.

Simulation1: Only one safe exit is opened (Scene1) and two safe exits are both opened normally (Scene2).

Simulation2: On the basis of scene 2, barriers are placed on the left exit of the first floor of the dormitory building (Scene3), on the third floor (Scene4), and on the fifth floor (Scene5) (Simulating fire and other emergencies).

Simulation3: The occupant distribution is adjusted on the basis of scene 2 (Scene6).The female postgraduates are arranged to live on the first floor and the second floor, the male PhD students are arranged to live on the fifth floor and the sixth floor, and the female PhD students are still arranged to live on the third floor and the fourth floor. The specific distribution after adjusting is shown as Table III.

The three-dimensional model of evacuation simulation of the dormitory building is shown in Fig. 4.

TABLE III. THE NUMBER OF PEOPLE ON EACH FLOOR IN DORMITORY BUILDING AFTER ADJUSTING (PER)

Floor	Floor1	Floor2	Floor3	Floor4	Floor5	Floor6	Total
Number	192	192	96	94	95	90	759

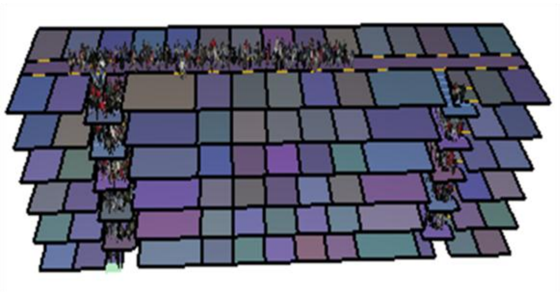

Figure 4. Evacuation simulation model of dormitory building

IV. SIMULATION RESULTS AND ANALYSIS

A. The Effect of Pre-evacuation Time on Evacuation Performance

By simulating the two simulations of Scene1 and Scene2, it shows that the evacuation time is 441.3s when only one safety exit is opened and it is 241.5s when two safe exits are opened. The trend chart of the remaining and the exited occupants over time of Scene1 and Scene2 are shown Fig. 5 and Fig. 6 respectively. Comparing the two figures, we find that evacuation time is shorten by nearly 200s in Scene 2, which has great significant for the safety evacuation during an emergency.

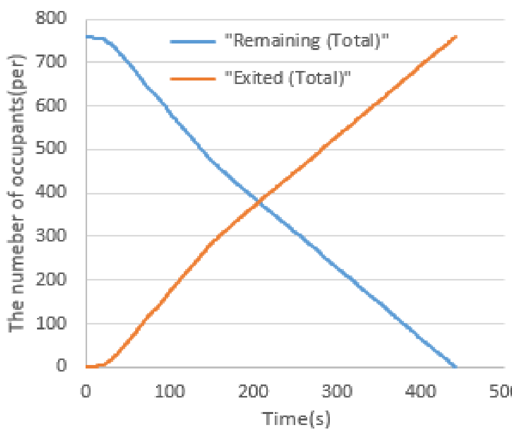

Figure 5. The remaining and the exited /time of scene1.

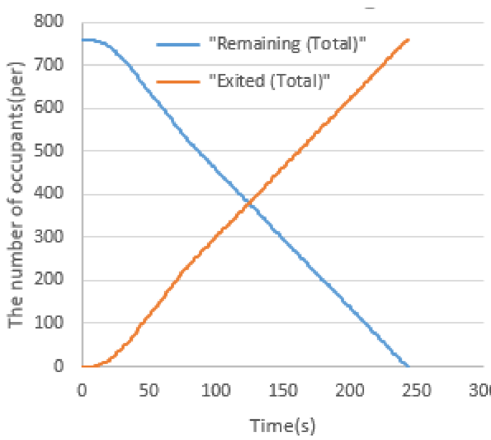

Figure 6. The remaining and the exited /time of scene2.

The human traffic of the west and the east exit of floor1of Scene1 and Scene2 are shown in Fig. 7 and Fig. 8 respectively. It can be seen from Fig. 7 that the flow rate of the left stair exit is far greater than that in right when only the left side exit is opened. This indicates that most people choose to evacuate from the left stairway whether they live in the upper or lower floor. Thus, there happens the congestion in the left staircase while there are only dozens in the right stair, which results in reducing the utilization rate of the staircase and exit, prolonging the total evacuation time and reducing evacuation efficiency. As shown in Fig. 8, we can see that the flow rate of both stair exits are identical basically when two safety exits are opened. This indicates that both left and right stairs can be effectively utilized, which will greatly reduce evacuation time, improve evacuation efficiency and reduce casualties.

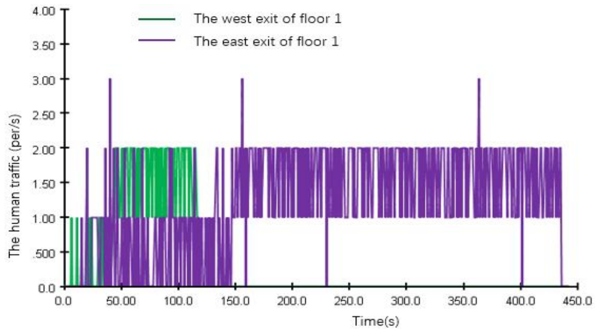

Figure 7. The human traffic of the west and the east exit of floor1 in Scene1.

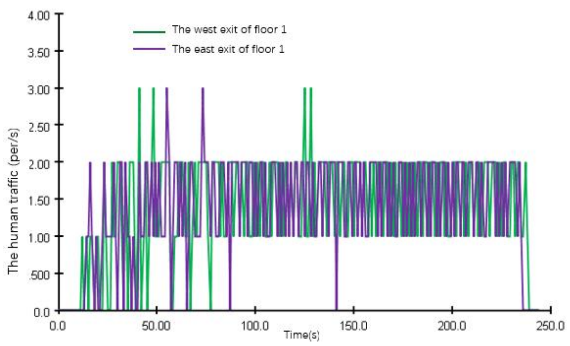

Figure 8. The human traffic of the west and the east exit of floor1 in Scene2.

B. *The Influence of Obstacles on Evacuation Performance*

In order to study the influence of obstacles (Simulating fire and other emergencies) on evacuation performance, the dormitory building is simulated according to the design of simulation 2 and the following analysis are conducted. In this simulation, the position of the obstacle is shown in Fig. 9. Only the position of the obstacle on the first floor is shown (The location of the obstacle on the third and fifth floor are the same as on the first floor).

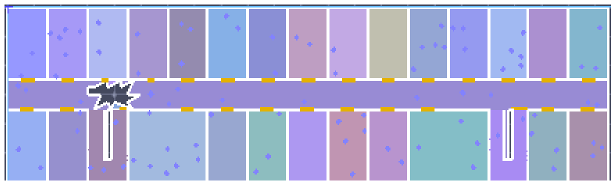

Figure 9. The location of obstacle in floor1.

It is concluded that the total evacuation time of Scene3, Scene4 and Scene5 are 457.8s, 419.5s and 365.8s from the simulation process respectively. This indicates that the higher the level of the obstacle on the floor, the less the total time of evacuation when the occupant choose the shortest distance to evacuate. The three scenes are analyzed in detail as following.

When the barrier is located near the left exit of the first floor, the evacuation process is shown in Fig. 10. It can be seen from it that the majority of people still wait on the right stairs even if the left stairs of the fifth floor and the sixth floor are empty, which results in most of the evacuation time is wasted in waiting and crowding. This shows that the occurrence of emergency have a certain effect on the psychology of people. Since people have a psychological fear of emergencies, they prefer to wait rather than get close the barriers, thus it extends the evacuation time.

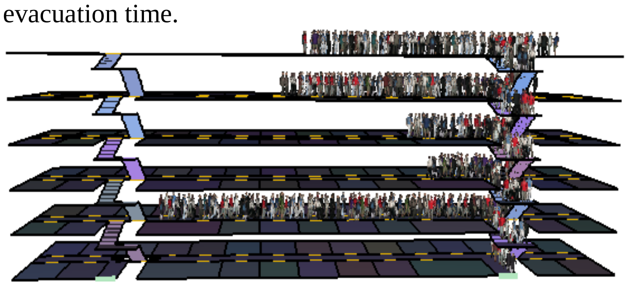

Figure 10. The drawing of occupant evacuation

When the obstacle is located near the left stair of the third floor, the evacuation route of the second floor selected for analysis is shown in Fig. 11. Comparing the evacuation path nearing the left and right side of the stairway, it was found that the people on the right side of the staircase are congested, and the left and right paths are disconnected. This means that people evacuated from the top level are stuck on the second floor, waiting to escape from the left side, no one choose to escape from the far left exit, so the evacuation time is extended. To verify the accuracy of this phenomenon, the simulation was conducted when the obstacle is located near the left staircase of the fifth floor. The simulation results are shown in Fig. 12.

As shown in Fig. 12, the left stairway is empty and the remaining occupants are waiting to evacuate on the right staircase when the evacuation time is only 120.3s. Occupants from the fifth and sixth floor still chose to wait at the right stairway of the fourth floor, rather choose to walk more than 100 meters to the left stair in order to complete the escape faster. This reduces the utilization of stairs and the evacuation efficiency. Therefore, it proved that the shortest distance is not the best evacuation route during evacuation.

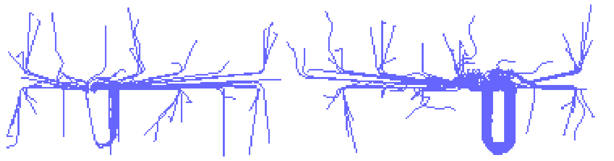

Figure 11. The evacuation route map of floor2 of Scene4.

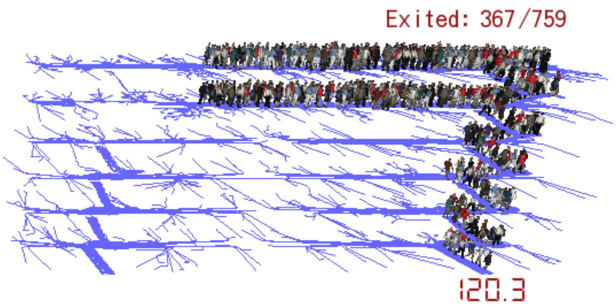

Figure 12. The evacuation route map of Scene5

C. *The Effect of Occupant Distribution on Evacuation Performance*

The simulation results after adjusting the current occupant distribution shows that the total evacuation time is 236s. Although it is only about 10s less than the evacuation time in Scene1, 10s means hundreds of lives in an emergency. Therefore, occupant distribution is also important for emergency evacuation. Fig. 13 shows a significant difference of the above six scenes. Compared with the six curves and Table IV, it can be seen that the total evacuation time is the least after adjusting occupant distribution, and the evacuation rate is stable relatively, which indicates that there is no congestion. In other cases, apart from Scene2, the evacuation rate changed greatly, which indicates that congestion occurs during evacuation. The total evacuation time of each scene are shown in Table IV.

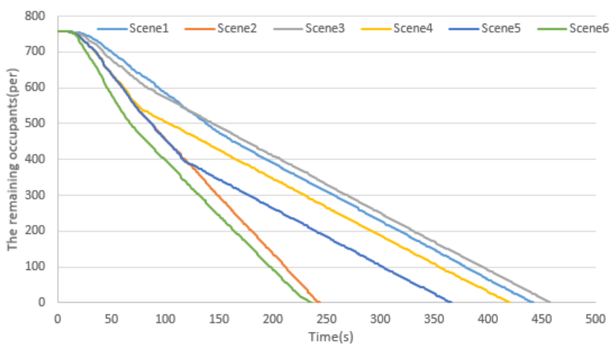

Figure 13. The remaining occupants/time of every scene.

TABLE IV. THE EVACUATION TIME OF DIFFERENT SCENES

Scene	Scene1	Scene2	Scene3	Scene4	Scene5	Scene6
Evacuation time (s)	441.3	243.5	457.8	419.5	365.8	236

V. DISCUSSION

A. *Summary of Findings*

The purpose of this study is to test the influence of safety exit setting occupant distribution and the location of obstacles on the emergency evacuation efficiency in old dormitory building. Furthermore, some suggestions about emergency management are put forward for dormitory administrators. This article summarizes and discusses the main findings of this article as follows.

1) When the reaction time is too long, the evacuation time will be extended and the evacuation efficiency will be reduced greatly;

2) The safety export setting and occupant distribution will have a significant impact on the emergency evacuation of the dormitory building;

3) The shortest distance is not the best evacuation route during evacuation.

B. *Implications*

The results of this study are of great significance to the security research and the actual emergency evacuation of dormitory buildings. It can provide important reference and warning function for administrators of dormitory or university residential buildings. In practical application, managers can change the current unreasonable exit setting of dormitory buildings, rearrange the occupant distribution. At the same time, the dormitory management center should organize and lead dormitory managers and residents to conduct emergency evacuation drills, which will reduce evacuation time and improve evacuation efficiency and reduce casualties in emergencies greatly.

C. *Limitations and Future Research*

This study shows that the research results have theoretical and practical significance. However, the study also has some limitations. For example, it lacks the object of old dormitory buildings in other universities and other units since the sample selected in this paper is limited to a certain old dormitory building in one university. Future research can further compare and analyze data from other units to obtain more accurate results. In addition, the study only illustrates the impact of the above three aspects on emergency evacuation through simulation, the influence degree and the influence path of them on emergency evacuation are not analyzed effectively. The future research can be discussed from this aspect in order to provide more theoretical guidance for the emergency administrator.

VI. CONCLUSIONS

In this study, a simulation model is adopted to study how pre-evacuation time, safety exit setting occupant distribution affect the overall evacuation times in a 6-story low-rise building. In our experiment, we analyze the evacuation situations and results by considering six different scenarios. And finally, some conclusions and suggestions are put forward as follows.

1) The administrators should strengthen safety education and training for residents, improve response sensitivity of occupants in response to an emergency in order to shorten response time. In addition, it is necessary for occupants to strengthen the training of emergency drill and reduce the fear of them caused by emergencies, so as to complete the evacuation more quickly.

2) When the setting of safe exit is modified in the old dormitory buildings, the safety evacuation time can be greatly reduced and the emergency evacuation efficiency can be improved more deeply and comprehensively. Therefore, we recommend that universities should change the status quo of only one safe exit of the old dormitory building, guarantee both safe exits can be opened normally. In addition, dormitory administrator should be on duty in each safety exit and strengthen the safety education and training for dormitory management personnel.

3) Arranging occupant distribution reasonably can reduce evacuation time. Therefore, it is recommended that the management center of dormitories should allocate the residents reasonably according to the characteristics (the age, gender, psychological quality, etc.) of occupants and the actual number of residents in each floor. For mixed dormitory, men should be arranged on the higher floors and women on the lower floors since most men walk faster than women in general; for separate quarters for men and women, fewer residents is arranged on a higher floor, with other staff on lower floors.

This paper facilitates a more profound understanding during an emergency evacuation by which pre-evacuation, security exit settings, occupant distribution and evacuation route of occupants affect evacuation efficiency. The specific theoretical and practical implications will also lead emergency management researchers to pay more attention to security exit setting and management behavior in order to improve evacuation efficiency. Conclusions can serve as important strategies and tactics for the improvement of both theories and practices related to emergency management of dormitory.

Conflict of Interest

The authors declare no conflict of interest

Author Contributions

Yan Li conducted the research; Yan Zhang analyzed the data; Yan Zhang wrote the paper; all authors had approved the final version.

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Yan Li, born in Shanghai in 1979, has the following educational background: Ph.D., Safety Technology and Engineering, Xi'an University of Science and Technology, Xi'an, 2014; Master, Enterprise Management, Xi'an University of Science and Technology, Xi'an, 2006; Bachelor, Accounting, Xi'an University of Science and Technology, Xi'an, 2000. Current research focuses on identifying social network communication process of the miners' unsafe behavior and risk factors for, and strategies to prevent, injuries related to work, and the built environment.

She is an associate professor of Safety Technology and Engineering at Xi'an University of Science and Technology, She has published more than 20 academic papers in the core journals of China and the international reviews.

Yan Zhang, born in Heze, Shandong in 1994, has the following educational background: Master's degree, Industrial Engineering, Xi'an University of Science and Technology, Xi'an, 2017-present; Bachelor, Security Engineering, Liaocheng University, Liaocheng, 2017. Current research focuses on identifying social network communication process of the miners' unsafe behavior and risk factors for, and strategies to prevent, injuries related to work, and the built environment.

She is a master student of Industrial Engineering at Xi'an University of Science and Technology, She has published 4 academic papers in the core journals of China and the international reviews.

Jianping Jiang, born in Heze, Shandong 1972, has the following educational background: Master's degree, Xian University of Architecture and Technology, Xi'an, 2007. Current research focuses on building environment and engineering.

He is an associate professor of Shanghai Institute of Technology, He has published more than 10 academic papers in the core journals of China and the international reviews.