Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 11 (2011) 273–279
Engineering Procedia

The 5th Conference on Performance-based Fire and Fire Protection Engineering

The Study on Safety Evaluation of Evacuation in a Large Supermarket

LIANG Qiang[a] JIN Hong-yu[a,*]

Department of Fire Fighting Commanding, Chinese People's Armed Police Force Academy,Langfang, China

Abstract

Supermarkets are typical crowded public places where the accident caused by evacuation congestion in any emergency event happened easily. In this paper, the number of customers, the ratio of personnel's age, the walking speed and other basic datas were obtained by present observation in a typical supermarket. On this basis, the evacuation scenarios were simulated by buildingEXODUS software for this supermarket and the safety performance was analysed. At last, the safety measures of supermarket management for evacuation were proposed.

Keywords: large supermarket;occupant safety evacuation;buildingEXODUS;original data of Evacuation

1. Introduction

Supermarket has special business models and consumption concepts, which provides customers more convenience, veritable boon, and full range of goods. Thus, it becomes the first choice for urban shopping. The supermarket has a few floors, whereas, the area of a single floor is large, usually up to several thousand square meters. In addition, there are a great number of combustible items, and the personnel density is high. Moreover, shelves are everywhere in supermarket, then people may easily get lost when they choose goods around, so it is difficult for them to find the evacuation directions, and more difficult to identify the emergency exits. Once some unexpected accidents, e.g. fire, occur, it is likely to happen tramples resulting in the injury or death of a large number people if people cannot be evacuated on time [1]. In this study, pedestrian traffic data such as pedestrian flow, pedestrian flow rate and density, and parameters, e.g. pedestrian's age, gender were collected via on-site and video observation from the entrances and exits of over time [2,3]. Based on the data, the buildingEXODUS software was used to simulate the evacuation process. Then the emergency evacuation strategy for the supermarket was optimized by simulating the main issues of evacuation.Considering the building structure, shelf layout,

* Corresponding author. Tel: +86316-2068561; Fax: +86-316-2068561.
E-mail address: liangqiangy@eyou.com.

1877–7058 © 2011 Published by Elsevier Ltd. Open access under CC BY-NC-ND license.
doi:10.1016/j.proeng.2011.04.657

characteristics of evacuation people groups and daily business management, we provide evacuation measures to ensure the safety of people in the supermarket, and also provide effective references for other supermarkets.

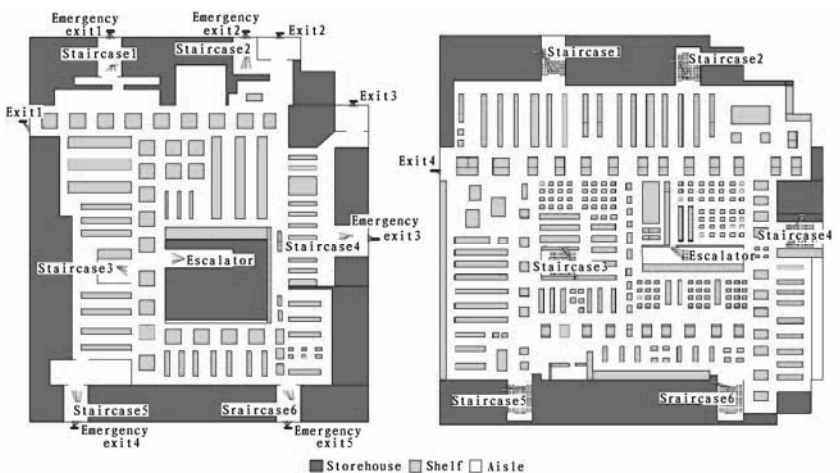
Nomenclature

M_i the retention people number of floors in a time period
M_{i-1} the retention people number of the previous period
M_{EN} the number of people entering floors of this period
M_{EX} the number of people exiting floors of this period

2. Building structures and supermarket personnel basic data collection

2.1. Overview of building structure

For large-scale supermarkets, building structure and shelf layout are the prerequisites to affect the evacuation. In this paper, a supermarket in Hebei Province was studied as the research object, which has 2 floors. The area of first floor is 7730m^2, and there are totally eight exits, of which three are usually used and the other five are emergency exits. Also there is one escalator connecting the second floor and six emergency evacuation stairs. The building area of the second floor is 8525.5m^2, and there is only one commonly used exit, and one escalator connecting the first floor and six emergency evacuation stairs. Figures 1 show the building plan and the positions of every exit and staircase. The dimensions of each exit and stair are provided in Table 1.



(a) First floor (b) second floor

Fig. 1. schematic diagram of simulation space

Table 1. The dimensions of each exit and staircase

exit and staircase	Width (*m*)
Exit 1、4	2
Exit 2、3	3
Staircase	3
Escalator	3
Emergency Exit 1、2、3	4
Emergency Exit 4、5	3

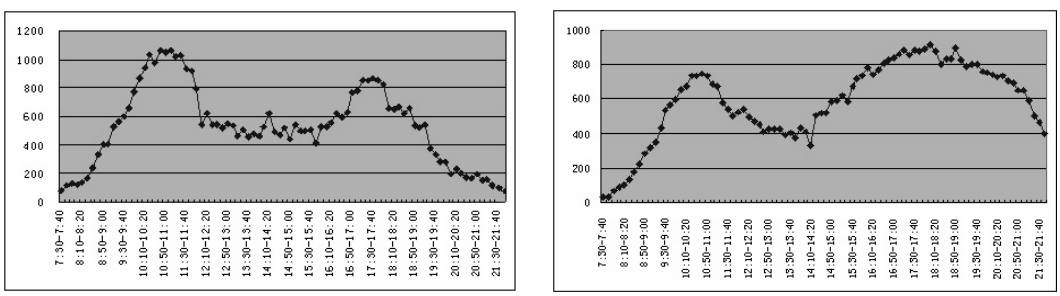
2.2. The basic data collection of personnel

The number of personnel in the supermarket is a continuous changing numerical value from the open time to the close time. The number of people in each period is related to the number of the previous period as well as that of entering and exiting people in this period. The observation was started from the beginning of business to the end of the business by sub-period statistics. And record the number of people entering and exiting each floor every ten minutes for a measurement time interval. The stopwatch was used to time, and the counter to count the number of people. The number of people in supermarket was recorded by on-site monitoring. The following are monitoring places: (1) entrances and exits of every floor; (2) escalators and stairs between each floor and the previous one. We set up group numbers according to the number of monitoring places, and each group has two people. They measure the number of people who enter and exit or the number of people who go up and down stairs and escalators respectively.

The retention people number of each floor at certain period based on the survey results is calculated as follows:

$$M_i = M_{i-1} + M_{EN} - M_{EX} \quad (1)$$

The number of people who are on the ascending escalators and stairs is counted into the number of upper floor; meanwhile the number of people who are going down is counted into the number of lower floor. Figures 2 indicate the respective curve of personnel changes of the first floor and second floor in every period of opening time. From the results, we can see that the peak numbers of the first floor and the second floor reach 1062 and 918 respectively, which occur respectively at 11:00-11:10 am and 18:00-18:10 pm.



(a) First floor (b) second floor

Fig. 2. the respective curve of personnel changes in every period of opening time

The gender, age of the recorded personnel was also analyzed through the on-site observation and video observation method, and then we obtain the basic data required by evacuation simulation, e.g. the composition proportion of the supermarket personnel, people horizontal walking speed, the speed of going up stairs and the speed of going down stairs. Table 2 provides the detailed data.

Table 2. original data of evacuation in supermarket

the composition of the supermarket personnel	Under 15 years old		15-40 years old		40-60 years old		Up 60 years old	
	Male	Female	Male	Female	Male	Female	Male	Female
proportion（%）	3.0-5.0	2.0-6.0	15-30	15-30	12-24	16-34	2.0-15	3.0-18
horizontal walking speed（m/s）	0.5-0.7	0.4-0.7	1.2-1.6	1.0-1.4	1.2-1.6	0.9-1.3	0.5-0.8	0.4-0.8
the speed of going down stairs（m/s）	0.6-1.0	0.5-1.0	0.5-0.9	0.5-0.8	0.5-0.9	0.5-0.8	0.5-0.8	0.5-0.8
the speed of going up stairs（m/s）	0.65m/s；0.5m/s							

3. Introduction of BuildingEXODUS software and setting of simulation conditions

3.1. Introduction of BuildingEXODUS software

BuildingEXODUS [4] is a software package used for simulation of the evacuation of large people number in complex building structures, e.g. supermarkets, hospitals, cinemas, railway stations, airports, schools, and other complex high-floor buildings, especially for safety evaluation, calculating evacuation capacity of the various structures. Using buildingEXODUS, the interaction between people and people, people and fire as well as people and the buildings can be considered. The model is based on a series of criteria to determine the behavior and movement of persons, such as choosing the nearest exit firstly, the larger weight person winning when competing the same location and so on. These guidelines are divided into five sub-models of interaction: personnel sub-model, mobile sub-model, behavior sub-model, toxic and hazardous sub-model, as seen in Figure 3. All sub-models work on the geometric structure of the simulated building.

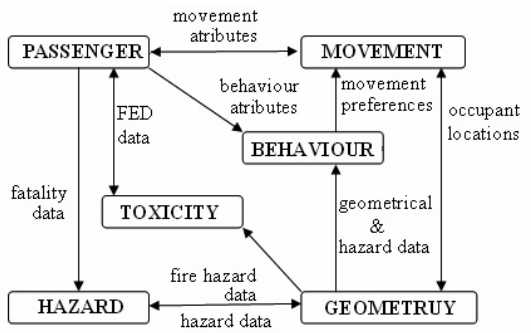


Fig. 3. EXODUS sub-model interaction

3.2. Settings of the basic evacuation data and personnel behaviors

The data required by simulation such as the number of personnel, age and sex ratio, the horizontal walking speed of people, the speed of going upstairs and downstairs are set according to survey results of Section 2.2. The pre-evacuation time of personnel is randomly set by computer according to the set range varying from 30 second to120 second. According to the number of people and the internal structure of the supermarket, the initial positions of personnel in the supermarket are randomly distributed. To compensate the increase of the number of personnel on holidays, we increase the total number by 30% on holidays from a security point of view.

Panic behaviors usually occur in emergencies, which directly affect the evacuation efficiency [5]. In buildingEXODUS, we take two measures as follows to simulate panic behaviors. First, choose extreme behavior among behaviors. People would become "impatient" when they show extreme behavior, which increases the possibility of choosing the other evacuation paths and even re-selecting exits. Secondly, increase the conflicting resolution time. Through the conflict resolution time, BuildingEXODUS indirectly considers that personnel density would reduce the travelling speed. After showing panic behavior, the chance of conflict between people would increase because each person wants to leave the supermarket quickly. The value set of the conflict punishment time is shown in Table 3.

Table 3. The value set of the conflict punishment time

	Normal behaviors (s)	Panic behaviors (*s*)
First level	0.5~0.7	2.0~2.5
Second level	0.8~1.5	3.2~4.0

In order to more accurately indicate behaviors of people in the process of the evacuation, personnel behaviors are set as follows:

Angle of Movement: since buildingEXODUS belongs to cellular automaton model, the evacuation route is usually a curve. This behavior is to make people as much as possible to maintain their own motion directions in the evacuation, keeping straight line evacuation routes.

Avoid Pop. Density: this act allows people to avoid some high personnel density areas in the evacuation.

Extreme Behavior: this act means that people would have such behavior of finding other exits and as much as possible trying for mobile location when the queuing time is beyond that of their patience.

Milling: this act makes people are in a random walk state before the evacuation.

Stair Packing: in the acquiescent stairs simulation of buildingEXODUS, people always try to ensure one step interval distance away from the one before them to walk, that is, everyone occupies two steps, but this behavior makes people walk side by side, i.e. each person can only occupy one step.

3.3. Selection of evacuation route

Personnel evacuation routes of BuildingEXODUS are decided by the nodal potential, people tend to move toward the lower nodal potential node. In the real evacuation process, however, sometimes people tend to evacuate through their familiar paths. In this situation, people may choose some familiar exits but farther ones. This behavior can be simulated by the nodal potential biased exits, namely, adjusting the nodal potential of exits attracts people , and then decide people's evacuation paths. In the simulated supermarket, customers are more familiar with exits 1, 2, 3 of the first floor, exit 4 of the second floor and escalator according to the survey. Hence, nodal potentials of the above exits are all set by 120, and others are all 100.

4. Evacuation simulation result analysis

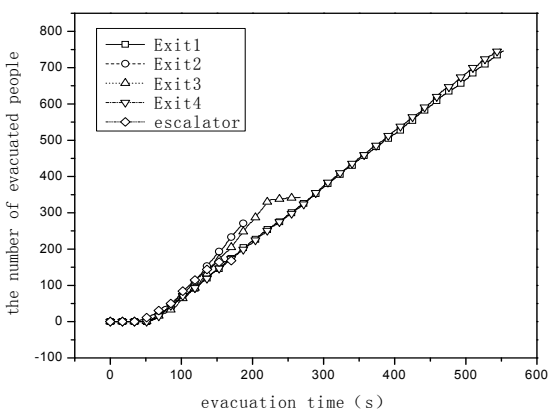


Fig. 4.the number of evacuated people in exits and escalator

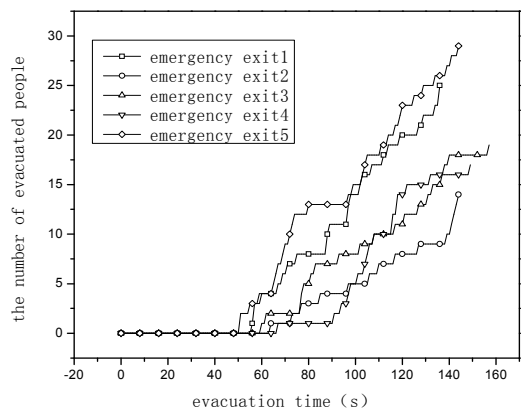


Fig. 5. the number of evacuated people in emergency exits

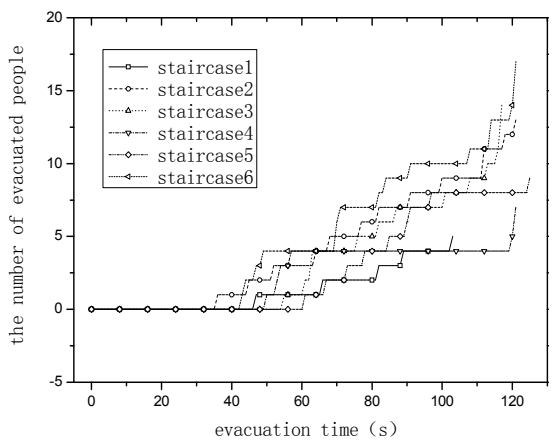


Fig. 6. the number of evacuated people in each staircase

Figure 4 provides the curve of the number of evacuated people over time in every exits as well as escalator. Figure 5 shows the variation of the number of evacuated people in emergency exits at different time, and Figure 6 is the curve of the number of evacuated people over time in each stair. The total evacuation time is 547 seconds. The total time of evacuation is 552s and 547s for the first and second floors respectively. As the pre-evacuation time is of random distribution varying from 30s to 120s, the time for the first person evacuated out from all exits of both first and second floors is after 50s, while it is after 40s for all the staircases of the second floor. As can be seen from Figures 4,5,6, the number of evacuated people in each exit and staircase is significantly different, and exits except those that are usually familiar with people are in much low utilization. In the first floor, exit 1 has the most evacuated people. The number is 747 and the time of evacuation is 552s; From exits 2 and 3, 272 and 343 people evacuated. The time is 132s and 136s respectively. The number of evacuated people from emergency exit is much less than that of the above exits, and the numbers are all below 30. In the second floor, most people evacuated through exit 4. The number is 752 and the time is 547s. The utilization of the escalator leading to the first floor is much higher than the other stairs. The number evacuated from escalator is 163, while people evacuated from other stairs are all less than 20. The possible reason for such result is people's first reaction is to go to the most familiar exits 1, 2, 3, 4 and escalator to leave, when unexpected emergent accident occurs. Due to lacking of guidance as well as people's herd mentality, the utilization of emergency exits and connected staircases is relatively low. Thus, bottleneck effect occurs in the exits that people are familiar, and these places are most likely to cause congestion and stampede.

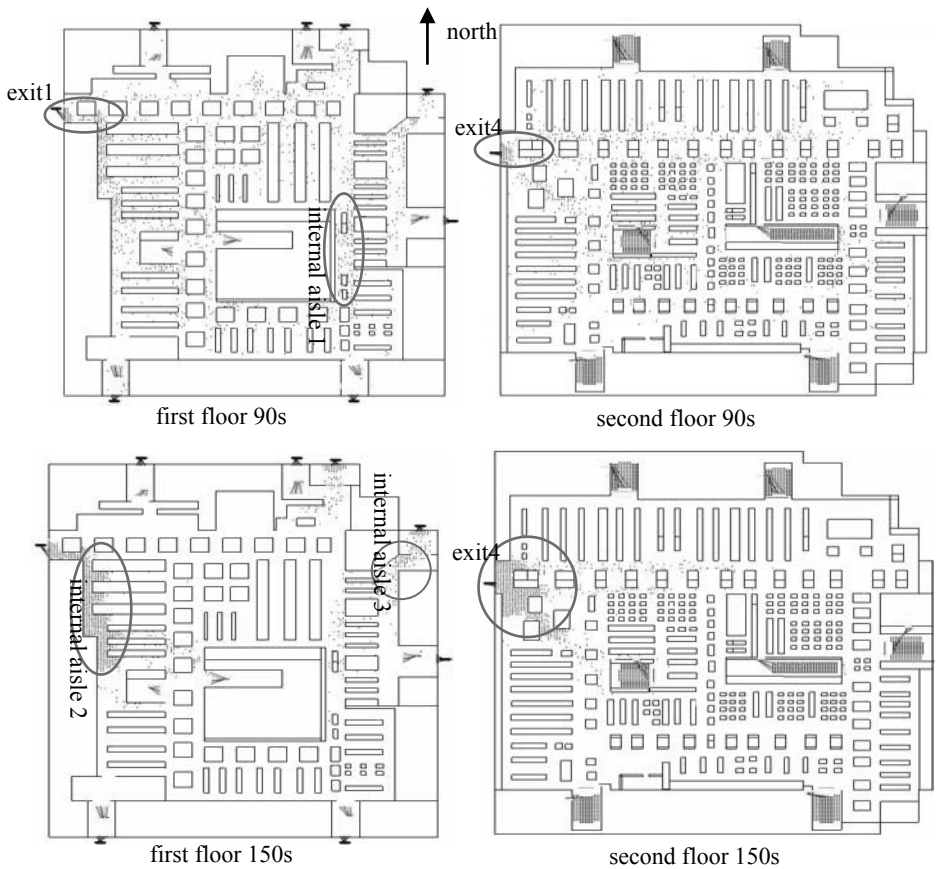


Fig.7. the evacuation process of every floor at different time

Figure 7 shows the evacuation process of every floor at different time. From this figure, we can see that five main places are easily to form bottleneck effect. The main bottlenecks are the delineated positions, i.e. exits 2 and 4 and internal aisles 1,2,3.Reasons of causing exits 1 and 4 to be bottlenecks are as follows. (1) The evacuated people are not familiar with the location of emergency exits, and then much more people are congested in familiar exits; (2) in

order to maximally use the space of supermarket, businessmen put cargoes near to the exits, which blocks the evacuation of people; (3) checkouts are set in exits 1 and 4, which reduces the actual available width of exits. Bottleneck of aisle 1 is caused by the reduced effective width because of the shelves in the aisle. Bottleneck of aisle 2 is caused by the unreasonable displayed shelves. If the west-east aisle is changed to north-south aisle, this bottleneck of the crowd will be reduced. Bottleneck of internal aisle 3 is due to the evacuation channel that is convergent channel before exit 3. If the 90° corner can be removed, the evacuation will be smoother.

5. Measures to improve evacuation conditions

From the simulation results of the supermarket evacuation, the results show that the layout of buildings and shelves, the manage department and evacuation teams play the most important roles in improving the evacuation conditions.

- The manage department should post the positions of evacuation channels widely, and try to enable the customers could read the information conveniently. When the accident happens, the manage team members should direct the customers to evacuate safely and orderly. Especially, some security team members should be arranged nearby the common exits and emergency exits to evacuate customers and improve the efficiency of exits.
- Reducing the pre-evacuation time could decrease the total evacuation time significantly. The emergency radio should be played immediately once the accident happens. To reduce the evacuation time, the manage team members should broadcast the accident information directly. In addition, it is important to stabilize the motions of customers to avoid the panic of population and ensure the evacuation orderly.
- Set the evacuation signs properly. Hang the guide signs at the end and crosses of shelves. To form continuous visualization, a series of directional light (or store light) signs should be set on the ground or the shelves near the ground, with the sign arrows pointing to security exits.
- In terms of the layout of the shelves, it is necessary to avoid the complex plane distribution of shelves, ensure the width of the intra-aisle, and inhibit putting the fixed or portable shelves. The direction of the shelves should be set according to the position of exit to make it be orthogonal to the exit as possible.
- The form of the evacuation aisles should be simple and straight without curling, stairs, and doorsills, to reduce the collision and fall off. If the swerves are necessary, make the walls of aisles as parallel as possible, and avoid the shrinking of the walls. In addition, it is important to ensure the valid width of the entrances and exits, and avoid the putting shelves nearby the entrances and exits.

Acknowledgements

This work was supported by National Key Technology R&D Program during the 11th Five-Year Plan Period of China- No.2006BAK08B02.

References

[1] You Yuhang, Li Yuanzhou, Chen Jinsong. Preliminary Study on Evacuation Design in Large Supermarket[J]. Engineering Science. Apr. 2007, Vol.19 No.14

[2] YOU Yu-hang,LI Yuan-zhou,ZHOU Ji-wei. Preliminary investigation for occupant density in large supermarket[J]. FIRE SCIENCE AND TECHNOLOGY. 2007,26（4）: 360-362

[3] Zhang Shu-ping,Jing Ya-jie. Research of evacuation crowd in the business hall of large department stores[J]. FIRE SCIENCE AND TECHNOLOGY. 2004,23（2）:133-136

[4] buildingEXODUS user guide and technical manual revision 4.00, FSEG, University of Greenwich.

[5] Li Sheng-li,Wei Dong,Liang Qiang. Study on evacuation efficiency of ticket gate and escalator under panic behaviour. FIRE SCIENCE AND TECHNOLOGY. 2010,29（2）