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Evacuation Simulation and Emergency Management Optimization in Urban Residential Communities

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Abstract. Urban residential communities usually have high density of residents. Timely and securely evacuation of residents in communities is of great importance during unexpected disasters or emergency events. To conduct better evacuation process in residential communities, this paper proposes a new framework of evacuation simulation and emergency management optimization. Compared with the traditional methods, the advantage of the proposed method lies into three aspects: (1) The new method highlights the easy-crowded areas in both indoor and outdoor evacuation. (2) Family behaviors are considered in evacuation. (3) Detailed emergency management optimization measures are spatially described on maps based on the analysis of the evacuation simulation results. A case study in Changhongfang Residential Community, Xuhui District, Shanghai, China was conducted to demonstrate the feasibility of the proposed method.

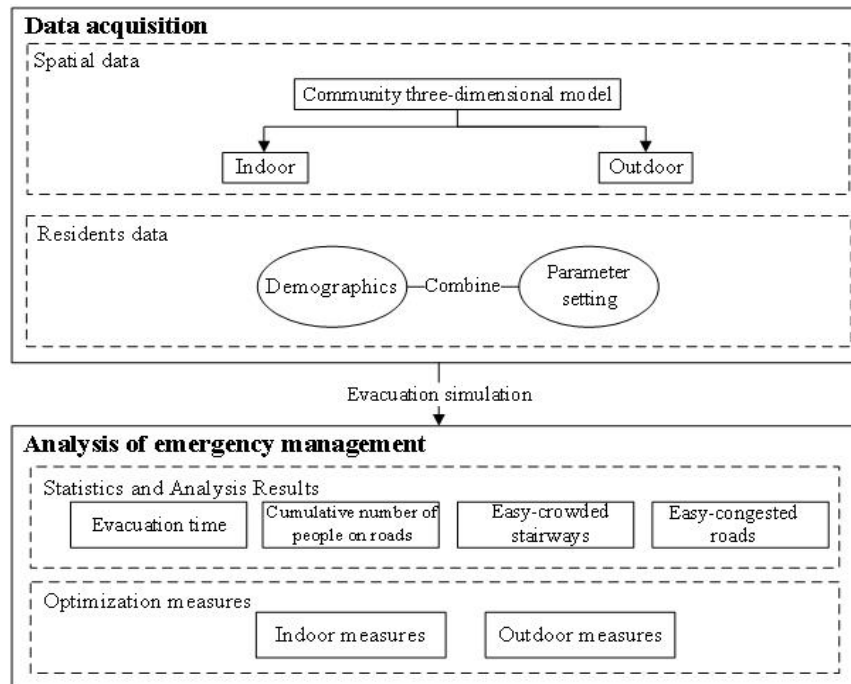
1. Introduction

Disasters may lead to substantial destruction of physical infrastructure and heavy economic losses [1]. Urban population exposures to both natural and technological disasters are increasing globally [2]. In recent years, the urbanization of China is accelerating and the population is increasing rapidly in expanding cities. This situation leads to that emergencies may occur with a larger probability. However, if people do not evacuate effectively in emergency, it may bring disastrous consequences [3]. For example, a stampede was happened in Shanghai Bund in December 31, 2014, which made 36 people died and 49 people injured. To mitigate the adverse effects of emergencies on urban population, better evacuation planning and emergency management is essential in disaster management [4].

This paper presents a new framework of evacuation simulation and emergency management optimization. The framework considers family behaviors and integrates indoor and outdoor evacuation simulation. Analyzing the evacuation simulation process, it can easily present statistics and analysis results, such as the evacuation time, the cumulative number of people on roads, the easy-crowded stairways and easy-congested road sections. With such detailed analysis of the evacuation simulation results, the framework can provide detailed management optimization measures of emergency evacuation for improving the efficiency of evacuation and reducing evacuation risks. A case study in Changhongfang Residential Community, Xuhui District, Shanghai, China, was conducted to demonstrate the feasibility and applicability of the framework.



2. Framework



Figurer. 1. Framework of the proposed method. This framework integrates a simulation procedure of residential communities and emergency management analysis and optimization.

2.1. Data acquisition

Spatial data. Two types of spatial data are required in the framework: building data and road data, which are the basics of simulation. Building data contain apartments, corridors and stairways. Road data include roads in residential community, parking lots and exits.

Resident data. Resident data contain demographic data and characteristics of different residents. Demographic data can be obtained from the property companies or census data in the scale of communities, which include the total number, the sex ratio and the age group of residents, etc.

In this paper, four behavioural characteristics of residents are proposed as follows:

(1) Evacuation mode: Residents will evacuate their homes after all family members getting together. (2) Walking speed: The walking speeds of residents can be classified in accordance with the age and gender groups. (3) Spatial distribution: The spatial distribution of residents in communities can be acquired by demographic data or reasonable estimation methods of building population. (4) Physical traits: It is necessary to obtain the shoulder widths of residents which depend on body measurements or experiential data of previous studies.

2.2. Evacuation simulation

After acquiring the spatial data and resident data, the evacuation process can be simulated to show the whole dynamic process of residents' evacuation from rooms in buildings to the exits of a community. The scenarios developed for evacuation simulations are relative to two representative unreasonable management problems in communities: (1) stacked sundries on stairways, and (2) haphazardly parked vehicles on roads.

In the evacuation simulation, the three-dimensional space of the residential community is abstracted as a three-dimensional triangular grid model. The speed of a resident moving to the next grid depends on the occupant density, the distribution of obstacles in the forward direction, and the maximum moving speed [5].

According to Euler formula, the speed and position of people in the next movement can be shown as:

$$\bar{v}_{next} = \bar{v}_{curr} + \bar{\alpha} \times \Delta t \quad (1)$$

$$\bar{p}_{next} = \bar{p}_{curr} + \bar{v}_{next} \times \Delta t \quad (2)$$

where Δt is the time step; \bar{p}_{curr} is the current grid position of a resident; \bar{v}_{next} is the speed of a resident moving towards the next direction; \bar{p}_{next} is the position of the next grid; $\bar{\alpha}$ is the turning acceleration; \bar{v}_{curr} is the current speed of a resident.

2.3. Emergency Management Optimization

In this section, simulation results, which include evacuation time, cumulative number of people on roads, easy-crowded stairways and easy-congested roads, under four scenarios are discussed. According to the simulation results, emergency optimized measures can be proposed to improve evacuation efficiency.

Statistics and Analysis Results. Evacuation time: Evacuation time of residents in buildings can be compared with prescribed time made by Architectural design code for fire protection [6], which stipulates that the allowable time for safe evacuation of general civil buildings should be less than 6 minutes.

Cumulative number of people on roads: This indicator can highlight the road sections which have larger cumulative number of people during evacuation. This represents that more people had passed the road sections. Special attentions should be given to these road sections during evacuation because of more evacuation risks.

Easy-crowded stairways: Easy-crowded stairways are deduced by comparison of simulations with different distribution of stacked sundries in stairways. Sundries occupy indoor evacuation space during emergency evacuation, hinder residents' actions, cause congestions, and reduce residents' evacuation efficiency.

Easy-congested roads: Easy-congested roads are concluded from the different spatial distribution of haphazardly parked vehicles on roads. Most of the existing urban residential communities in China lack of necessary parking spaces. Haphazardly parked vehicles on roads may cause congestions in the communities, which seriously impedes the evacuation of residents [7].

Optimization measures. Optimized measures for emergency management include indoor and outdoor measures based on the above indicators in "Statistics and Analysis Results" section. These measures provide a scientific basis to reduce casualties as much as possible.

Indoor measures: Identify the easy-crowded stairways and set up warning signs at the corners of the stairways. Residents in buildings, especially whose households are close to easy-crowded stairways, should try not to pile sundries in corridors. The property company should pay attention to floors relative to easy-crowded stairways when carrying out routine safety inspections in buildings.

Outdoor measures: Identify easy-congested roads and set guide signs in conspicuous places on the side of these roads. The property company should replan parking lots in non-easy-congested roads. Residents need to avoid easy-congested roads when parking vehicles in the community.

3. Case study

3.1. Study area

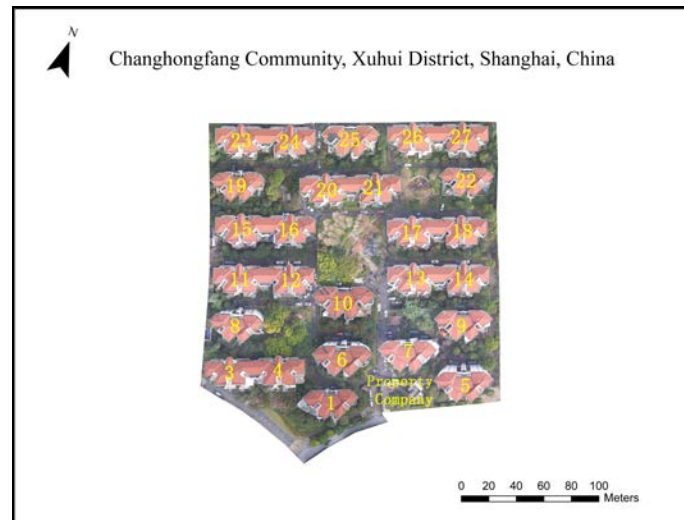


Figure. 2. Aerial photo of Changhongfang Community with a resolution of 0.03m. The study area, Changhongfang community (Fig. 2), which was built in 1991, is located in Xuhui District, Shanghai, China. There are totally 18 unit buildings in this community, including 4 four-story buildings, 3 five-story and 11 six-story buildings. Two exits located in the north and south of the community, respectively. Sundries are often piled in the stairways of the buildings in the study area. At present, the community is also facing with the problem that parking space cannot meet the increasing demand of private cars.

3.2. Spatial data and resident data

We acquired the indoor and outdoor spatial data of the study area. The key indoor sections of a building include apartments, corridors and stairways. Indoor data were obtained by the household design drawing of buildings and field surveys. The essential outdoor Sections of contain roads, parking lots and exits. Outdoor data were obtained by unmanned aerial vehicle (UAV). The complete three-dimensional model of the study area can be built by integrating the indoor data and outdoor data.

Resident data were also obtained according to the Sixth National Census of Shanghai in 2010. There were totally 1654 permanent residents lived in Changhongfang Community.

Characteristics of different residents were also obtained by literature data reviews and field surveys. Figure 3 shows that members in a family will gather in their room or on roads as a unit to evacuate together [8].

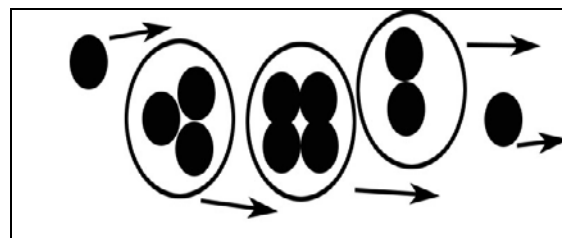


Figure. 3. Sketch map of evacuation mode in buildings (Big circles represent whole families, smaller ones represent residents).

During the whole evacuation process, walking speeds differ by age-groups. Among the people who belong to the same age-group, their speeds follow a normal distribution.

Table 1 shows the speeds of different age-groups. The speed data is adopted from a pedestrian speed measurement in People's Square and Nanjing Road Pedestrian Street in Shanghai in 2003 [9].

Table 1. Speed of different age-groups.

<i>Category</i>	<i>Speed (m/s)</i>	<i>Number of samples</i>
Elderly woman	1.08	246
Middle-age woman	1.20	621
Yong woman	1.27	1002
Elderly man	1.10	286
Middle-age man	1.25	829
Yong man	1.32	949

Before the evacuation simulation, we should also assume the initial spatial distribution of residents. In this case study, it is assumed that residents live in buildings with even distribution.

The shoulder widths of different age groups in the case study were set as Table 2 [10].

Table 2. Shoulder width of different age groups.

<i>Age group</i>	<i>Shoulder width</i>
Elderly woman	39.0
Middle-age woman	39.5
Yong woman	38.0
Elderly man	40.5
Middle-age man	41.9
Yong man	41.0

3.3. Simulation results

Based on the spatial data and residential data of the study area, the evacuation simulations in different scenarios were executed and different simulation results were generated. With the analysis of the simulation results, key indicators of evacuation processes, including the evacuation time, cumulative number of people on roads, easy-crowded stairways and easy-congested roads, can be evaluated.

Evacuation time.

Table 3. Evacuation time under scenario with stacked sundries on stairways and haphazardly parked vehicles on roads.

<i>Total time (S)</i>	<i>Average evacuation time in buildings (S)</i>			<i>Road evacuation time (S)</i>
450	six-story building	four-story building	five-story building	445.1
	132.2	83.6	78.3	

The cumulative number of people on roads.

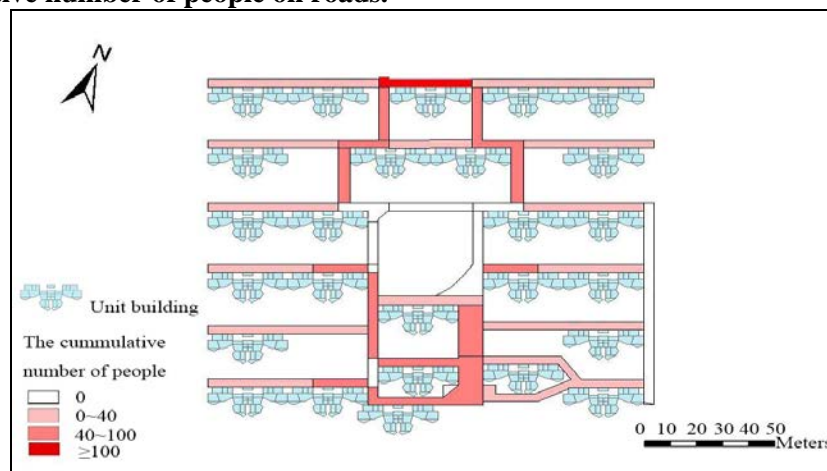


Figure 4. Cumulative number of people on roads in evacuation

Figure 4 shows the cumulative numbers of people on different road sections in the study area.

Easy-crowded stairways. The easy-crowded stairways illustrate that the floors which related to these stairways are more likely to have crowd situation in evacuation if there are stacked sundries on these floors. After comparing the evacuation simulation results, the easy-crowded stairways in six-story buildings are the 1st floor, 2nd floor and 3rd floor. In five-story and four-story buildings, the easy-crowded stairways are the 2nd floor, and 1st floor, respectively.

Easy-congested roads.

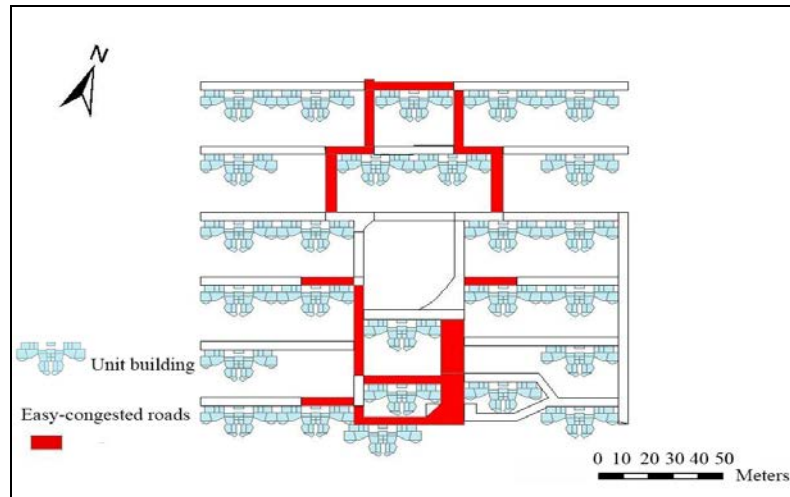


Figure 5. Spatial distribution of Easy-congested roads in Changhongfang community.

Figure 5 represents the easy-congested road sections which are mostly distributed in the T-junctions of the roads and near the exits of the community.

3.4. Optimization measure

The objective of the evacuation simulation and result analysis is to optimize the emergency management and reduce the risk in evacuation. We present the optimization measures for emergency management by indoor measures and outdoor measures, respectively.

Indoor measures: Identify the easy-crowded stairways and set up warning signs at the corners of the stairways in the building, especially at the stairways of lower-floor (below the third floor). The warning signs remind that the residents should not to pile sundries in corridors and . The property company of the community should pay attention to the lower floors when carrying out routine safety inspections in buildings.

Outdoor measures: Identify easy-congested roads and set guide signs in conspicuous places on the side of these roads. Residents should avoid parking vehicles on easy-congested roads in the community. The property company should replan parking lots in non-easy-congested roads. Figure 6 shows the "No Parking" and guide sign on roads and recommended parking roads. With the geospatial analysis, the easy-congested roads in the community have been spatially identified in Figure 5. Based on the analysis of this figure, we recommended the locations of the "No Parking" signs and the guiding signs on the side of roads. The distribution of the recommended parking roads are also generated. Such a vehicle parking proposal can help the property company of the study area better allocating vehicle parking spaces.

The indoor and outdoor optimization measures can provide scientific and technical support and detailed proposals for evacuation management in the residential community. The local decision-makers can utilize the detailed spatial optimization measures to improve emergency evacuation management and reduce residents' evacuation risks in disasters or emergency events.

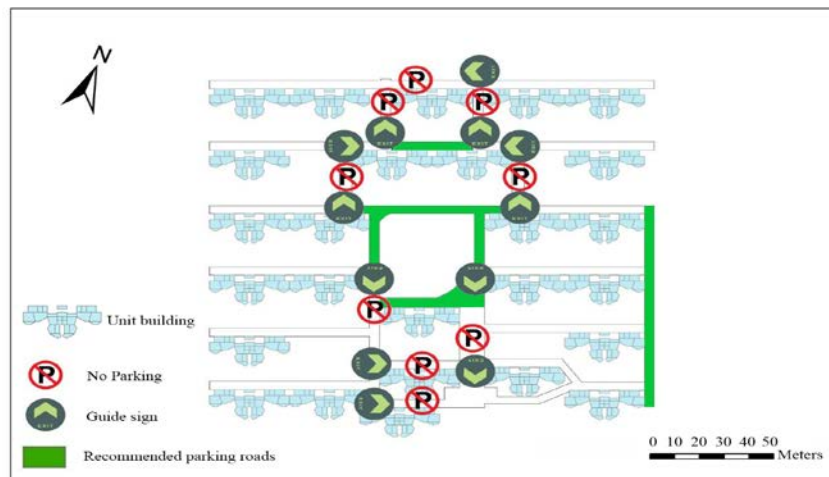


Figure 6. Outdoor optimization measures for evacuation management

4. Conclusion

This study proposed a new method for evacuation simulation and emergency management optimization in urban residential communities. The proposed method highlights the importance of quick and secure evacuation in emergency management. It integrates indoor and outdoor evacuation processes of residential communities as a whole for obtaining the optimization measures of both indoor and outdoor to improve evacuation process. Family behaviors can be set for residents in evacuation simulation. Two types of obstacles involved in evacuation are considered, including stacked sundries on stairways and haphazardly parked vehicles on roads. Simulation results under different scenarios can be analyzed to generate both indoor and outdoor optimization measures for evacuation management.

A case study in Changhongfang Community, Xuhui District, Shanghai, China was conducted to demonstrate the feasibility of the proposed method. Through evacuation simulation, detailed evacuation time, including roads evacuation time and buildings evacuation time, were got. The optimization measures included the location of the "No Parking" signs and the guiding signs on roads, the recommended parking roads were put forward to further improve the evacuation efficiency and reduce the risks. The proposed method can be easily applied in other similar case studies.

5. Acknowledgments

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6. References

- [1] Trivedi, A., Singh, A.: A Hybrid Multi-Objective Decision Model for Emergency Shelter Location-relocation Projects using Fuzzy Analytic Hierarchy Process and Goal Programming Approach. *Int. J. Proj. Manag.* 35, 827--840 (2017)
- [2] Haines, A., Kovats, R.S., Campbell-Lendrum, D., et al.: Climate Change and Human Health: Impacts, Vulnerability and Public Health. *Public Health.* 120, 585--596 (2006)
- [3] Yu, J., Zhang, C., Wen, J., Li, W., Liu, R., Xu, H.: Integrating Multi-agent Evacuation Simulation and Multi-criteria Evaluation for Spatial Allocation of Urban Emergency Shelters, *Int. J. Geogr. Inf. Sci.* 32, 1884--1910 (2018)
- [4] Lim, H.R., Lim, M.B.B., Piantanakulchai, M.: Determinants of Household Flood Evacuation Mode Choice in A Developing Country. *Nat. Hazards.* 84, 507--532 (2016)
- [5] Zhao, Z., Chen, Q., Wang, H., et al.: Guidance Evacuation based on Pathfinder Model Under The Emergency State in Public Place (in Chinese). *Fire. Sci. Technol.* 32, 1327--1330 (2013)

- [6] GB50016-2014.: Architectural Design Code for Fire Protection (in Chinese). China Planning Press, Beijing (2015)
- [7] Qu, C.: Problems and Countermeasures in Car Parking in Urban Residential Areas in Our Country (in Chinese). *Urban. Stud.* 22, 23--26 (2015)
- [8] Wu, D.: Study on Safety Evacuation of High-Rise Residential Building in Fire Condition (in Chinese). Tianjin University of Technology (2009)
- [9] Chen, R., Dong, L.: Observations and Preliminary Analysis of Characteristics of Pedestrian Traffic in Chinese Metropolis (in Chinese). *J. Shanghai Univ.* 11, 93--97 (2005)
- [10] GB10000-88.: Human Dimensions of Chinese Adults (in Chinese). Standards Press of China, Beijing (1988)