Large scale traffic evacuation simulation

based on multi-agent modeling

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Abstract

Traffic evacuation is one of the most important issues in the area of emergency management, and the selection of evacuation exit is the key to improve evacuation efficiency. Due to great difficulties in field experiments of emergency traffic evacuation, this paper presents a new type of traffic evacuation simulation system which could analyze the impact of the number and the location of evacuation exits and population density on evacuation time, and decision-making support can be obtained on the basis of it.

Keywords: Traffic evacuation simulation system, evacuation exit, population density, decision-making support

Introduction

Traffic evacuation is the main way of large-scale emergency evacuation, and is an important part of emergency response. Experts and scholars in the field have constructed the simulation methods of different scenarios by the abstraction, integration and dynamic coupling of various traffic simulation models.

In earlier research, the evacuation is considered a special traffic event which involves completely different driving behaviors and traffic management comparing with the normal way. On this account, a class for a certain type of disaster and evacuation simulation software emerged, such as NETVAC[1] was developed for evacuation of nuclear leakage accident, and MASSVAC[2] was for emergency evacuation of hurricane in city.

In recent years, with the mature and widely used ITS (Intelligent Traffic System) technology, the evacuation research tends to use simulation software based on ITS. There existing some popular such software, such as Paramics[3], CORSIM[4], MATSim[5], Integration[6], etc. ITS based traffic simulation software provides a lot of convenience for the evacuation simulation research, otherwise recent studies have shown that those software can't simulate emergency evacuation scenarios very well, and there are two reasons for this phenomenon.

There exists too many conditions and default information to evacuation simulation, for that most of the evacuees are likely to temporarily adjust the evacuation route.

The existing normal simulation software concerns only with traffic distribution and traffic control measures, while ignoring important contents such as background information of evacuation.

The traffic evacuation simulation system proposed in this paper is developed by Tsinghua University, and the accuracy and effectiveness of the system has been tested [7]. The system is on the analysis of microscopic evacuation model, characterizes heterogeneity based on dynamic parameters and models, establishes the microcosmic simulation models with heterogeneity and the numerical calculation models, and deduces the theoretical calculation errors, finally realizes the dynamic control of the calculation errors.

Agent and driving behavior models

Transportation is a complex system. Due to the driving variability, much attention has been paid on the simulation in normal situations and focus on various driving behaviors. The microscopic evacuation models used in the system are shown in Table 1. Car-following model consists of Gipps' model [8], Optimal Velocity Model (OVM) [9], Tampere model [10] and Intelligent Driver Model (IDM) [11]. Lane-changing models like MOBIL [12], describing when and how drivers change their lanes, were usually used with car-following models together. Intersection model is made up of signal light model [13], and models like Doniec's model (Doniec) [14] expanded the scope of car-following models from roads to crowded intersections. The path selection model uses the shortest path model [15] based on the A* algorithm, and also the model based on the potential energy network (simulated navigation equipment) [16]. The analysis model uses logit discrete choice model to make decision of departure time and destination [17][18]. The system also developed two simplified psychological cognitive models on the basis of the psychological model proposed by Spielberger [19] and Helbing [20].

The study uses a fuzzy value from 0 to 1 to measure the nervousness of an agent and use it to change other agent's parameters. It needs an external function to change the nervousness value. This paper assumes that it follows the logistic differential function. The value increases if the agent moves slowly and decreases if it drives fast.

$$\frac{dn_i(t)}{dt} = (2\eta_i(t) - 1)\frac{1}{t_r}\ n_i(t)\ \left(1 - n_i(t)\right),$$

$$n_i(0) = n_i^{(0)} \tag{1}$$

$$\eta_i(t) = \begin{cases} 0, & v_i(t) \geq V_{low}, \\ 1, & otherwise. \end{cases}$$

where t is the simulation time, n is the nervousness value of agent i, $n_i(0)$ is the initial value of n_i, t_r is the nervousness reaction time which refers to the time of an agent gaining its nervousness from 0.5 to $1/(1+e^{-1}) \approx 0.731$, Vlow is the threshold of speed in which an agent thinks it drives slowly, and $\eta_i(t)$ is the event that agent i drives in low speed. The system records the maximum nervousness value of each agent during simulation. An agent whose nervousness value is greater than 0.8 is regarded as a "panic" agent which will be focused in the experiment.

$$n_M(i) = \max_t n_i(t) \tag{2}$$

$$\xi(i) = \begin{cases} 1, & n_M(i) \geq 0.8 \\ 0, & otherwise. \end{cases} \tag{3}$$

where t is the simulation time, i is the agent's id number, $n_M(i)$ is the maximum nervousness value of agent i, and $\xi(i)$ is the panic event that agent i has been panic during the simulation.

An agent follows different behavior under anxiety or not, for example, people have a higher probability to run red lights and other herd behavior. The corresponding relationship between anxiety state and behavior pattern is shown in Table 2, and the corresponding relationship with the agent attribute is shown in Table 3.

Table1 Model library used in this system

Category	Model Name	Description	Literature
Car Following	Gipps Model	Driving model for safety	[8]
	OVM Model	Driving model for speed	[9]
	Tampere Model	Driving model for stability	[10]
	IDM Model	Driving model for smart	[11]

Lane Change	MOBIL Model	Deterministic lane changing model	[12]
	Lv Model	Probabilistic lane changing model	[21]
Intersection	Doniec Model	Intersection model with no signal	[14]
	Feng Model	Intersection model with signal	[13]
Path Selection	Shortest Path Model	Route selection model based on shortest distance	[15]
	Minimum Potential Energy Model	Route selection model with minimum driving time	[16]
Requirement analysis	Departure Logit Model	Discrete choice model for determining departure time	[17]
	Destination Logit Model	Discrete choice model for determining destination	[18]
Psychological model	Nervousness Model	A model for simulating the anxiety degree of evacuees	[19]
	Conformity Model	Herd behavior model of evacuees	

Table 2 The relationship between anxiety state and behavior pattern

Category	Non Anxiety	Anxiety
Car Following	Conservative Parameters	Radical parameters
Lane Change	MOBIL Model	Lv Model
Path Selection	Minimum Potential Energy Model	Shortest Path Model
Conformity Behavior	Low Probability	High Probability

Table 3 Relationship between anxiety state and agent attribute

Parameter	Non Anxiety $n_i = 0$	Anxiety $n_i = 1$
Maximum Acceleration (m/s^2)	2.0	4.0
Maximum Deceleration (m/s^2)	-2.8	-6.0
Maximum Deceleration of Front Vehicle (m/s^2)	-2.8	-6.0
Static Following Distance（m）	7	4
Lane Change（°）	10	20

The attributes of agent in anxiety state and non-anxiety state change in the linear relationship.

$$p = (1 - n_i)p_0 + n_i p_1$$

Where p is the agent's behavioral parameters, p_0 means the value in normal state and p_1 means the value in panic state.

Case Study

The evacuation time is of great significance in traffic evacuation. In this paper, a specific experiment is designed to study the relationship between the evacuation exits and evacuation time.

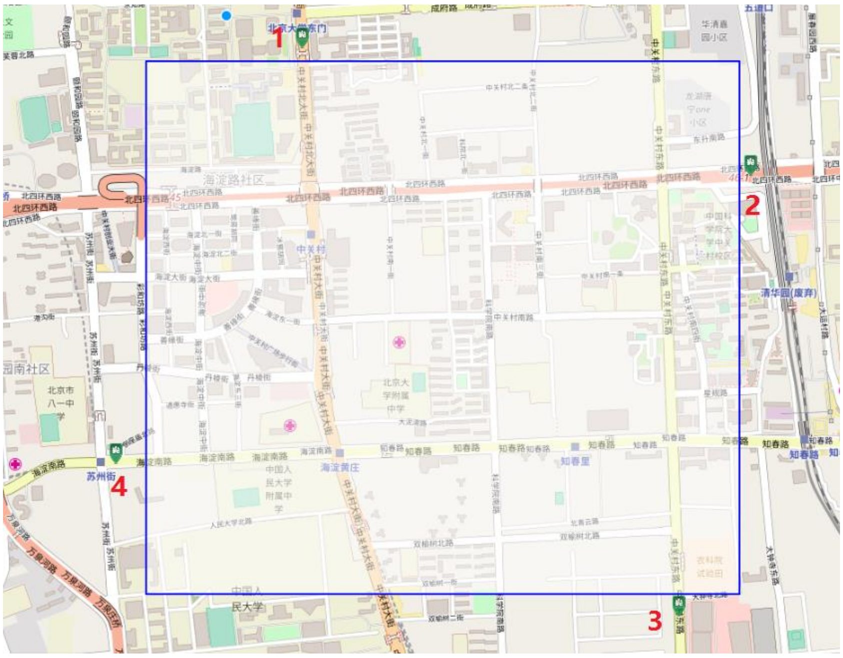

Figure 1 Emergency evacuation area

As shown in Figure 1, the experimental area is a busy area in Beijing, and simulation area is of 5.2694 square kilometers, including 4 exits. The study carried out five groups of experiments, designed as shown in Table 4, each group involves 9 tests through the establishment of different initial evacuation of the population.

Table 4 Experimental design

Number	Exit amount	Exit number	evacuation population
Group 1	1	1	Initial 5000 persons，each experiment increasing 2500， up to 25000.
Group 2	2	1&2	
Group 3	2	1&3	
Group 4	3	1，2&3	
Group 5	4	1，2，3&4	

Evacuation simulation results

Table 5 lists the linear fitting parameters of the evacuation time data after 5 groups of experiments which each of them consist 9 initial settings.

Table 5 The linear fitting parameters of the evacuation time data

Number	p_1*x+p_0 [p_1;p_0]	95% confidence interval	correlation coefficient	standard deviation
Group 1	0.269 10.01	(0.2615,0.2766) (-13.51,33.53)	0.9990	11.7787
Group 2	0.08785 52.47	(0.08314,0.09256) (37.8,67.14)	0.9964	7.3443

Group 3	0.1078	(0.1054,0.1102)	0.9994	3.7883
	34.9	(27.34,42.45)		
Group 4	0.05429	(0.04871,0.05988)	0.9869	8.7429
	52.8	(35.39,70.2)		
Group 5	0.04889	(0.0399,0.05787)	0.9594	14.0001
	27.81	(-0.213,55.84)		

According to the data in table 5, the correlation coefficient of each experiment is relatively high, the correlation degree is 0.9990, 0.9964, 0.9994, 0.9869, and 0.9594, respectively. It can be found there existing a high linear correlation between evacuation time and population density. The more exits, the more random selection of the crowd, which leads to the decrease of the evacuation time correlation and improvement of data dispersion.

Figure 2 shows the relationship between population density and evacuation time, the horizontal axis represents the population density (per square kilometer), the vertical axis represents the evacuation time (minutes). Each increase of 500 people per square kilometer, the average change of evacuation time corresponding to each group is increasing 269 minutes, 88 minutes, 108 minutes, 54 minutes and 49 minutes (Fig. 3). The second group and third group of experiments show that under the same condition of evacuation, the diagonal evacuation exits (such as the export of 1 and 3) performs much more better than side exits (such as the export of 1 and 2) , it can be proved by experimental evacuation time (108 minutes >88 minutes). Figure 4 shows the ratio of evacuation time between multiple exit and single exit at the same population density, the ratio is 0.4044, 0.4505, 0.2821 and 0.2239, respectively. Multi group data show that the result of the third experiment group is worse than second groups, and it can be known by Figure 1, the density of the roads and buildings around exit 1 and exit 2 is high, there needs to evacuate more population.

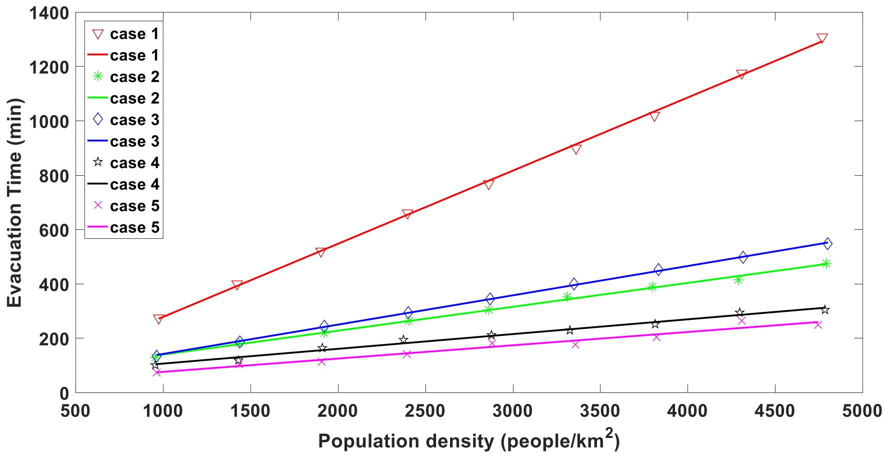

Figure 2. The relationship between population density and evacuation simulation time

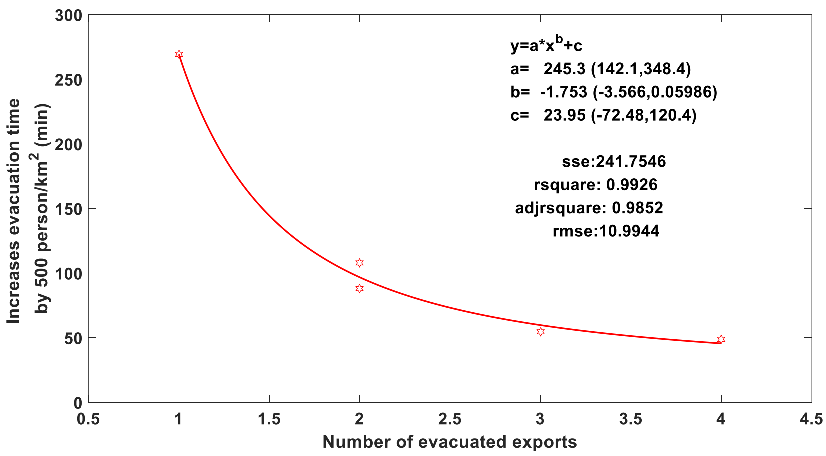

Figure 3 Population density increased by 500 people per square kilometer, the changes of evacuation time with different amount of exits

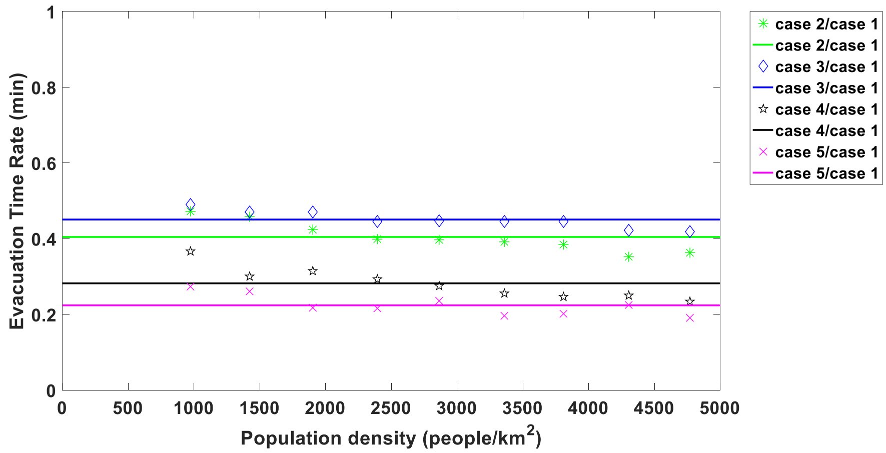

Figure 4. The ratio of evacuation time between multiple exit and single exit

Conclusions

This paper introduces a new type of traffic evacuation system, emphatically discusses the influence of the exit amount, location and population density on evacuation time, and the results can be used to traffic evacuation decision support.

In this paper, five groups of evacuation simulation experiments under different initial conditions are designed, and the experimental data are analyzed in detail. The main results are as follows:

(1) There is a highly positive linear correlation between evacuation time and evacuation population density. The evacuation time is related to the evacuation exit and nonlinear.

(2) Evacuation exits should be selected in areas with high population density.

In the future, we will consider additional factors (e.g., different types of vehicles, pedestrians, or bicycles) in the simulations for better understanding of evacuation-related decisions.

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References

[1] Sheffi Y, Mahmassani H, Powell W B. (1982) A transportation network evacuation mode[J], *Transportation Research Part A Policy & Practice* **16**, 209-218.

[2] Hobeika A G, Jamei B. (1985) MASSVAC: A Model for Calculating Evacuation Times under Natural Disasters[J]. *Emergency Planning*: 23-28.

[3] Cova T J, Johnson J P. (2002) Microsimulation of Neighborhood Evacuations in the Urban-Wildland Interface[J]. *Environment & Planning A* **34**, 2211-2229.

[4] Williams B M, Tagliaferri A P, Meinhold S S, et al. (2007) Simulation and Analysis of Freeway Lane Reversal for Coastal Hurricane Evacuation[J]. *Journal of Urban Planning & Development* **133**, 61-72.

[5] Lammel G, Grether D, Kai N. (2003) The representation and implementation of time-dependent inundation in large-scale microscopic evacuation simulations[J]. *Transportation Research Part C Emerging Technologies* **18**, 84-98.

[6] Mitchell S W, Radwan E. (2006) Heuristic prioritization of emergency evacuation staging to reduce clearance time[C]// *Proceedings of the 85th Annual Meeting Transportation Research Board*, Washington, DC, USA.

[7] Shengcheng Y. (2016) Study on Simulation Method of Traffic Evacuation for Emergency Decision Support. [D]. *Tsinghua University*.

[8] Gipps P G. (1981) A behavioural car-following model for computer simulation[J]. *Transportation Research Part B Methodological* **15**, 105-111.

[9] Bando M, Hasebe K, Nakayama A, et al. (1995) Dynamical model of traffic congestion and numerical simulation [J]. *Physical Review E Statistical Physics Plasmas Fluids & Related Interdisciplinary Topics* **51**, 1035-1042.

[10] Tampere C M J. (2004) Human-kinetic multiclass traffic flow theory and modelling: with application to advanced driver assistance systems in congestion[D]. *TRAIL Thesis Series*.

[11] Treiber M, Hennecke A, Helbing D. (2000) Congested traffic states in empirical observations and microscopic simulations[J]. *Physical Review E Statistical Physics Plasmas Fluids & Related Interdisciplinary Topics* **62**, 1805-1824

[12] Kesting A, Treiber M, Helbing D. (2007) General Lane-Changing Model MOBIL for Car-Following Models[J]. *Transportation Research Record* **1999**, 86-94.

[13] Weidong F，Lihua Y. (1999) Simulation of Signalized Intersection Based on Automatic Cell Model [J]. *Application Research of Computers* **7**, 47-48

[14] Doniec A, Mandiau R, Piechowiak S, et al. (2008) A behavioral multi-agent model for road traffic simulation[J]. *Engineering Applications of Artificial Intelligence* **21**, 1443-1454.

[15] Hart P E, Nilsson N J, Raphael B. (1968) A Formal Basis for the Heuristic Determination of Minimum Cost Paths[J]. *IEEE Transactions on Systems Science & Cybernetics* **4**, 100-107.

[16] Dommety G, Jain R. (1998) Potential networking applications of global positioning systems (GPS). arXiv preprint cs/9809079.

[17] Hasan S, Ukkusuri S, Gladwin H, et al. (2011) Behavioral Model to Understand Household-Level Hurricane Evacuation Decision Making[J]. *Journal of Transportation Engineering* **137**, 341-348.

[18] Mesa-Arango R, Hasan S, Ukkusuri S V, et al. (2013) A Household-Level Model for Hurricane Evacuation Destination Type Choice Using Hurricane Ivan Data[J]. *Natural Hazards Review* **14**,11-20

[19] Spielberger C D, Jacobs G, Russell S. (1983) Assessment of Anger: The State-Trait Anger Scale[J]. *Advances in Personality Assessment* **2**, 159-187.

[20] Helbing D, Farkas I J, Molnar P, et al. (2002) Simulation of pedestrian crowds in normal and evacuation situations[M]// *Pedestrian and Evacuation Dynamics*, 21-58.

[21] Lv W, Song W G, Liu X D, et al. (2013) A microscopic lane changing process model for multilane traffic[J]. *Physica A Statistical Mechanics & Its Applications* **392**, 1142-1152.