Study on Passenger Flow Simulation in Urban Subway Station Based on Anylogic

Yedi Yang
School of Computer Science and Information Engineering, Zhejiang Gongshang University, Hangzhou, China
Email: 780127184@qq.com

*Jin Li
School of Computer Science and Information Engineering, Zhejiang Gongshang University, Hangzhou, China;
Contemporary Business and Trade Research Center of Zhejiang Gongshang University, Hangzhou, China
*Corresponding author: jinli@mail.zjgsu.edu.cn

Qunxin Zhao
College of Foreign Languages, Zhejiang Gongshang University, Hangzhou, China
Email:1113197351@qq.com

Abstract—**In this paper, taking Hangzhou Metro Line 1 Wulin Square Station for example, we dynamically optimize the opening number of the entrance ticket windows at the station based on Anylogic pedestrian library, and study the impact of some parameters e.g. the pedestrian arrival rate and the opening number of the ticket windows in peak and off-peak periods, etc., on the average queuing number and utilization rate of the ticket windows. The aim is to provide a favorable reference and decision support tools for planners, designers, and operators. The simulation results show that for the off-peak period, that is, when the pedestrian velocity reaches to 1500/hour, opening two ticket windows can achieve the best average queuing number and the utilization rate of the ticket windows, and at the peak period, i.e. the pedestrian velocity is about 2500/hour, opening four ticket windows is the best strategy.**

Index Terms—**urban subway, pedestrian simulation, dynamic optimization, AnyLogic, queuing**

I. Introduction

In recent years, China's urban rail transit is developing in an unprecedented speed. According to the relevant statistics, in Mainland China, there have been 33 cities planning to construct rail transit, in which 28 cities have been approved. Hangzhou Metro Line 1 was opened on Nov.24, 2012, which is Hangzhou, even Zhejiang’s first subway line; Beijing opened four new Metro Lines on Dec.30, 2012, which were: Line6, Line8, the northern section of Line 9 and Line 10.

Undoubtedly, the subway relieves the traffic pressure to some extend, facilitates the movement of residents. We learned it from Hangzhou Hong Kong Metro Corporation Limited that on the first month of trial operation, the train ran totally 11,385 times. Averagely, it ran 379.5 per day, including 392 extra trains in weekdays' peaks. The total number of passengers was up to 4,378,667, and the daily amount was 14.5956 million. The maximum which appeared on December 9, 1999 (Sunday) was reaching 219,000. There are 30 sites and more than 200 ticket vending machines on Metro Line1, and a total of 1,653,696 one-way tickets were sold. The 3 stations with highest passenger flow are in turns as follows: Wulin Square, Hangzhou Railway Station, Lung Bridge.

However, with the growing of the passenger flows, the problem of people’s queuing for tickets becomes more and more severe. The time they spend on ticket queuing, and the number of queuing have the direct impact on passengers' experience of rail transit. The ticket sellers in the ticket window system contact with passengers directly, so the quality of their service has a great influence on the evaluation given by passengers. Therefore, in order to reduce the passengers’ queuing time, the prominent concern is to optimize the queuing system by opening ticket windows dynamically and reasonably in the process of operation which of course should at a reasonable cost. It can not only improve the competitiveness but also improve the quality of the service.

At present, many scholars have started carrying out researches concerning rail transit science and they have already been doing a lot of work. The former research can be divided into three categories according to the usage of the different methods. The first category is to establish a mathematical model to do the research of the railway ticket window system based on queuing system and routing optimization problem[1-10]. For example, Jitao Li and JunFeng Yang [1] from Dalian Jiaotong University who used the theory of queuing model to analyze the characteristics of the railway station ticket window queuing system, established a ticket windows optimization model based on the acceptable time of waiting, and gave a model of algorithm and processes.

doi:10.4304/jsw.9.1.140-146

Based on how to optimize the facilities, Qiwen Jiang [2] from Beijing Jiaotong University introduced the queuing theory, and correspondingly, the mathematical model. His study focused on the station automatic ticket machines, the station stairs and the station channel so as to optimize the configuration of the facility. In order to attract more passengers and improve operational efficiency, they provide their best service. The second category is to acquire the results by using simulation software such as Anylogic, simwalk, based on the theories such as Agent, queuing system [11-21]. For example, Lu Yu and Xi Zhang [11] from Beijing Jiaotong University used Anylogic simulation software systematically to analyze the layout of Beijing Xizhimen subway station rail transportation hub, passengers organizations streamline, and found the bottleneck of a guest stint distribution and also proposed some suggestions. Zhao Yafang [12] established a evaluation model of the layout of ticketing equipment and the configurable number by applying the method of queuing theory, which can analyze the arrangement form of the automatic ticketing equipment at the station and then raise up the proper form according to the place of the station. Based on the simulation software, Anylogic, the evaluation model can be verified. The third category is to do the simulation study by establishing physics models. For example, Guangzhou Transport Planning Institute's Yunbin He [21], through constructing a pedestrian simulation platform which based on the physical model of the hub, analyzed the relationship between the window average queuing number and ticket demand, and thus to know how many ticket windows are needed according to different queuing time. This article we dynamically optimize the number of the station pit mouth open ticket windows , based on Anylogic pedestrian library , taking Hangzhou Metro Line 1 Wulin Square Station as the background, and research the impact of parameters on the number of queuing and utilization of the window according to the pedestrian arrival rate and the number of the ticket windows open in peak and off-peak periods, providing a favorable reference for planners, designers, operators and decision support tools. At last, we come up with an improvement program which aims at the unreasonable facts after evaluating the rationality of the automatic ticketing equipment and the configurable number. And then the improvement program is verified.

This paper is organized as follows. The introduction to the Anylogic simulation principle, the scene of simulation and modeling process is described in Section 2. In Section 3, the specific analysis to the results of simulation is given. Finally, the concluding remarks are concluded in Section 4.

II. PRINCIPLES AND METHODS

A. Simulation Software

AnyLogic simulation software is used to create a professional virtual prototyping environment, and it is also designed for discrete, continuous and mixed behavior of complex systems. The AnyLogic can quickly build design system simulation model (virtual prototyping) and the external environment, including the physical equipment and operating personnel. Its applications include: control systems, traffic, dynamic systems, manufacturing, supply lines, logistics departments, telecommunications, networks, computer systems, machinery, chemicals, sewage treatment, military, education etc. The AnyLogic is powerful and flexible, and can offer a variety of modeling methods: object-oriented modeling method based on UML language, flowchart modeling method based on the square of Statecharts (state machine), which can be divided into ordinary and mixed, differential and algebraic equations, Java modeling.

Anylogic also includes the following standard databases which can be used to build the models rapidly. The Enterprise Library is mainly used to simulate discrete events which are related to manufacturing industry, supply chain, logistics resources, medical treatment etc. Solid models (trades, customers, products, components, vehicle etc.), technological processes (the typical working process, including wait, delay, resource utilization) can be built with the help of Enterprise Library. The Pedestrian Library concentrates on simulating a physical environment. It can be used to build a structure (Railway station, safety check etc) or a street which is full of people. The models can not only collect data such as density of pedestrians in different regions, but also calculate the efficiency of the load in service point. The simulation of interaction of pedestrians is complex behaviors' agent. However, The Pedestrian Library provides an advanced use interface which can build flow-process diagram of pedestrian quickly. The Rail Yard Library can help to build various railway shunting models and make it visually. Railway shunting model can combine discrete events and agents in order to simulate loading and unloading, allocating resources, maintaining business processes and other transport activities. Except those standard resources, users can build their own databases according to their own needs.

B. Simulation Scenarios

In this paper, we establish a subway entrance pedestrian distribution model, taking the Wulin Square Station in Hangzhou Metro Line 1 as the background, by designing different simulation environments and simulating passengers at the station distribution, to study the utilization of the facilities in the subway station and then to analyze. So we can provide support for the optimization of the rail transport. Figure 1 is a diagram of Hangzhou Metro Line 1 Wulin Square station. This station is an island platform with three layers. It looks like a rectangular solid with a length of 161.75 meters, a width of 36.6 meters and a depth of 27 meters.

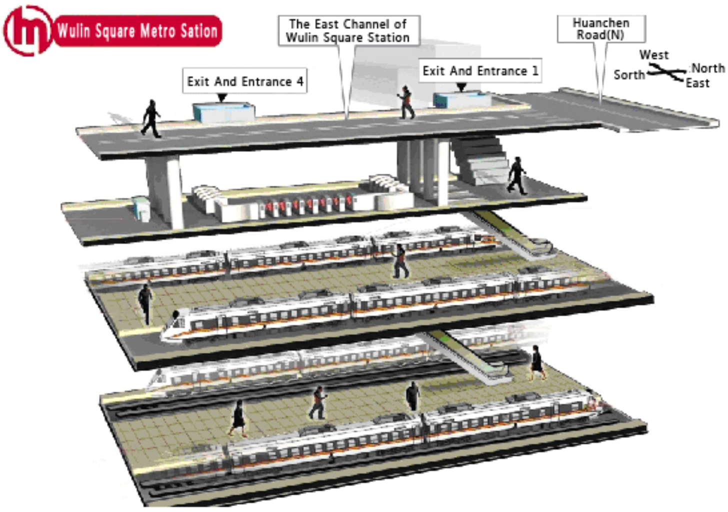


Figure 1. Space diagram of Hangzhou Metro Line 1 Wulin Square station in China.

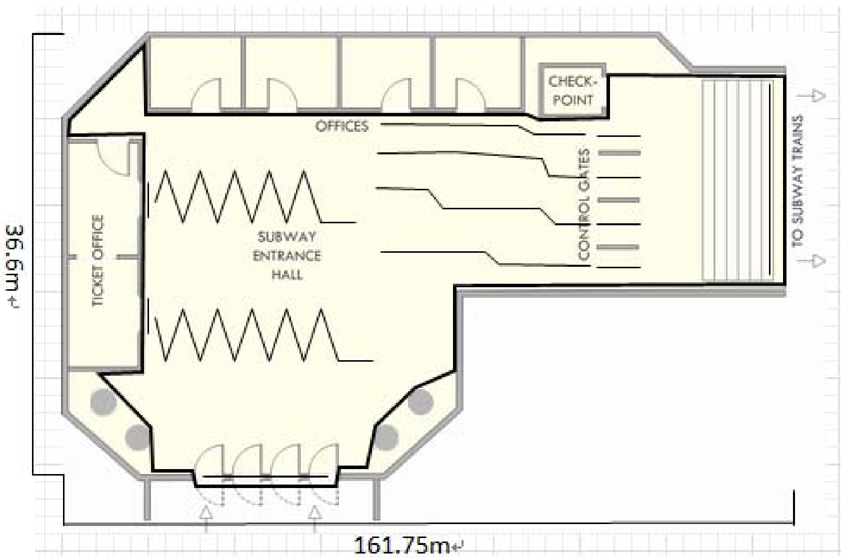


Figure 2. Subway entrance layout in the Anylogic simulation environment.

The top layer is the station hall; the middle layer is the device layer, and the following is the platform layer. This article will chose the top-level concourse level entrances as the simulation scene to simulation study, in Figure 2 is the site No. 4 in the Anylogic simulation environment at the entrance layout.

C. Research Principle

This article aims at evaluating comprehensively parameters such as pedestrian arrival rate and the number of the ticket windows opens which impact on queue length and utilization of the window, given the number of different scenarios, the best ticket booth. Wherein the average queue length is calculated as follows:

$$L_q = \sum L_{q,i} / N_i \tag{1}$$

Where L_q Indicates the queue's length, $L_{q,\mathrm{i}}$ is queue's length at the point of i, N_{i} indicates the total number of time points at the simulation. The window utilization calculation formula is as follows;

$$\partial = T_{\mathrm{m}} / T \tag{2}$$

Where ∂ indicates windows utilization, T_{m} is the working time for the window at simulation, T represents the total time at simulation.

D. Simulation Process

Wulin square, the subway no. 4 has four brake machine gates, the six automatic ticket offices (basically only four open) on the presence of the rush hour, the simulation environment is divided into peak and off-peak periods into two categories; the difference is the pedestrian arrival rate parameter settings. Combined with the actual passenger traffic, pedestrians to reach the peak of the rate is set to 2500/hour, and the peak of the pedestrian arrival rate is set to 1500/hour. The number of the port gates fixed to 4, the number of the ticket windows at different times from 1 to 6, setting the rate of pedestrians from 500-2500/hour, 500 rate interval, research in different pedestrian arrive rate, opening how many the ticket windows to ensure appropriate average queue length, and to get the maximum utilization of facilities.

When Passengers arrive at the station, someone who has public transportation card can enter into the station directly, but others should queue up for the ticket first. According to the site statistics, about 85% of the passengers do not need to queue up for the ticket, while 15% passengers have to wait in line. As shown in Figure 3 it is the inbound module map; queuing time for which the ticket windows obey the triangular distribution Triangular (15 * second (), 25* second (), 35*second ()), the service time of the wicket obey uniform (2.0 * second (), 3.0 * second ()) distribution.

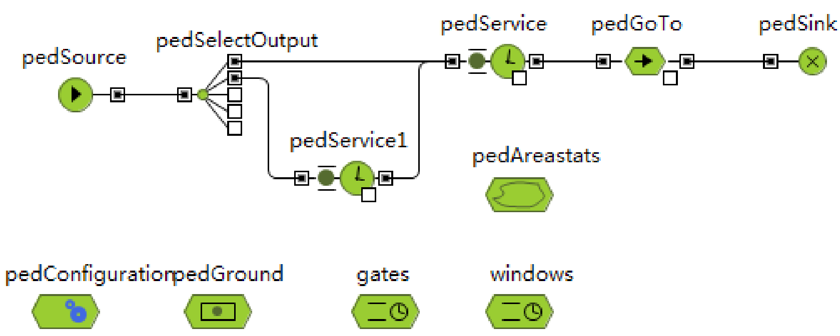


Figure 3. The subway entrance stint block diagram

TABLE I.
QUEUE LENGTH AND WINDOW UTILIZATION RATE IN THE 500 - 2500/HOUR WITH DIFFERENT WINDOW NUMBER

Rate (/hour) / Window's number	500	1000	1500	2000	2500
1	1 / 60%	15 / 93.3%	53 / 98.3%	75 / 100%	80 / 100%
2	0 / 10%	0 / 18%	2 / 65%	17 / 96.7%	47 / 100%
3	0 / 7.4%	0 / 14.3%	0 / 22.4%	1 / 28.3%	27 / 93.3%
4	0 / 4.3%	0 / 8.4%	0 / 15.3%	0 / 20.4%	20 / 86.7%
5	0 / 1.2%	0 / 4.3%	0 / 5.2%	0 / 7.1%	0 / 9.8%

III. SIMULATION AND DISCUSSION

A. *Analysis of the Simulation Results at Different Pedestrian Arrival Rate*

We simulated the queuing situation and the utilization rate of window under the following circumstances. The figure in the upper part of the sheet represents the average length of the queue at a certain window and a certain rate, and the figure in the lower part of the sheet represents the utilization rate of windows under corresponding circumstance.

As you can see from the sheet, different numbers of windows at different pedestrian arrival rate have an influence on the length of queue and the utilization rate of window. Obviously, on one hand, the more the ticket windows open, the shorter the length of queue will be and the lower the utilization rate of window will be. On the other hand, at a certain number of the ticket windows, the higher of pedestrian arrival rate, the longer the length of queue will be, accordingly, the utilization rate of window will be higher.

If analyzed the dates in the sheet separately, we found that the length of the queue and the utilization rate of window have positive correlation. But we hoped it could be passive correlation, that is, when the length of queue is shorter, the utilization rate of window will be higher. As far as we can see, it is not a fact. So, we are considering choosing the number of ticket windows that has the highest utilization rate within an acceptable length of queue. Then, we will analyze situations concretely, that is, in peak hours (the pedestrian arrival rate is 2500/hour) and in off-peak hours (the pedestrian arrival rate is 1500/hours).

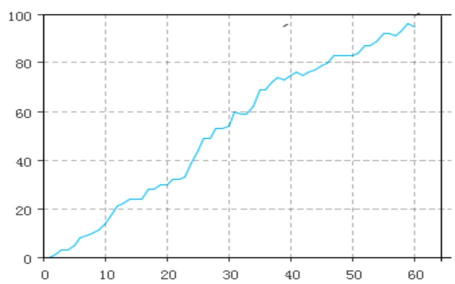
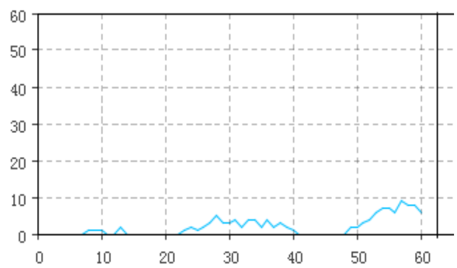
B. Analysis of the Simulation Results in Peak and Off-peak Hours

In off-peak hours, the pedestrian arrival rate is 1500/hour, the simulation results are shown as follows:

In off-peak hours, compared the utilization rate and the average passengers waiting in line, we realized that when there is one ticket window, the utilization rate is 98.33%, while there are two ticket windows, the utilization rate is 65%. Compared the utilization only, we could find out easily that the former is much larger than the letter. However, if we combine the number of passengers with it, we could find that the average passengers in situation 1 are 52.05 and the letter are only 2.02. When there are 3 ticket windows, according to the result of simulation, it can hardly form a line. Therefore, taking the utilization rate and the average passengers both into consideration, it is best to open two ticket windows in off-peak hours.

Figure 4 shows the simulation diagram when the ticket window number is 2. At its peak, the pedestrian arrival rate of 2500/hour number of different ticket booth under the simulation results shown in Table 3.

TABLE Ⅱ.
QUEUING AND UTILIZATION OF THE WINDOW WHEN THE TICKET WINDOW NUMBER IS IN THE OFF-PEAK PERIODS (1500/HOUR)

The Number of Ticket Windows	The Average Number of Queuing Passenger	The Utilization Rate of Ticket Windows	Line Chat of Queue Number
1	52	98.3%	
2	2	65%	
3	0	22.4%	—

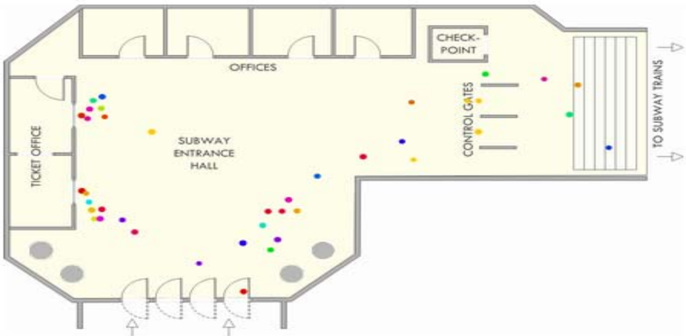
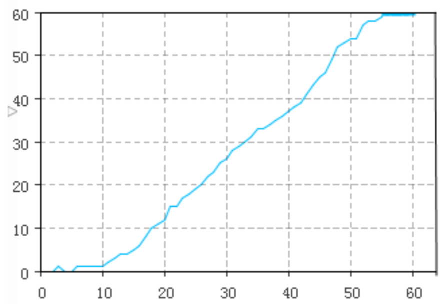
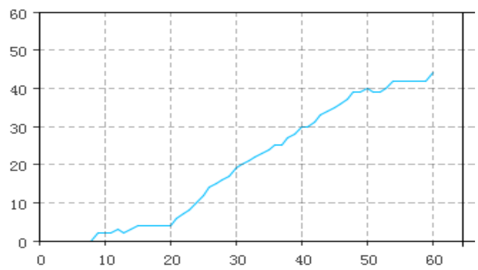


Figure 4. Off-peak hours queuing

TABLE III.
THE PEAK OF THE TICKET BOOTH NUMBER IS NOT THE SAME QUEUE AND WINDOW UTILIZATION

The Number of Ticket Windows	The Average Number of Queuing Passenger	The Utilization Rate of Ticket Windows	Line Chat of Queue Number
3	27.72	93.30%	
4	19.58	86.70%	
5	0	9.8%	—

When compared with the number of ticket windows in scenarios 3 and 4. Although there are more people queuing, it is a normal phenomenon considering the fact which will appear in the peak period. Utilization, the ticket window number 3 is slightly higher than the 4, and from the number of queuing point of view, the ticket window number 4 is better than 3. When the ticket window number is 5, we find that it hardly forms a queue in front of the ticket windows, but the window utilization is quite low. Therefore, the paper considers that open the four ticket window better during peak periods.

IV. CONCLUSION

We used the Anylogic to study the passenger flow at the entrance of Wulin Station, and after contrasting the different numbers of ticket windows according to different pedestrian arrival rate, we can draw a conclusion: During peak hours (the pedestrian arrival rate is 2500/hour), it is better to open 4 ticket windows. During off-peak hours (the pedestrian arrival rate is 1500/hour), it is better to open 2 ticket windows. As time is limited and the other subway lines in Hangzhou haven't been opened, the statistics of pedestrian arrival rate in peak and off-peak hours haven't been exactly determined in this article. The simulation model we used in this article can also be used in other subways' entrances, which can easily change the pedestrian arrival rate. Therefore, a more extensive study can be carried out on the distance between the ticket window and the ticket entrance. There is specific introduction about the application of the software in the second section.

ACKNOWLEDGMENT

The authors wish to thank the reviewers for their valuable comments. This work was supported in part by the Contemporary Business and Trade Research Center of Zhejiang Gongshang University which is the Key Research Institute of Social Sciences and Humanities Ministry of Education (Grant No.12JDSM16YB), Humanities and Social Sciences Foundation of Ministry of Education of China (Grant No. 12YJC630091), Zhejiang Provincial Natural Science Foundation of China (Grant No. LQ12G02007), the National Natural Science Foundation of China (Grant No.71171178), and Zhejiang Provincial Commonweal Technology Applied Research Projects of China (Grant No. 2013C33030), National Training Programs of Innovation and Entrepreneurship for Undergraduates (No.3080JQ43130 17).

REFERENCES

[1] Jitao Li, JunFeng Yang, Jia Fu, "Simulation Optimization of the Queuing System in front of Railway Station Ticketing Office," *Railway Transport and Economy*, pp.67-70, December 2007.

[2] Qiwen Jiang, "Research on Allocation Optimization for Entering and Leaving Facility in Urban Railway Transit Station," In: *Beijing Jiaotong University*, 2009.

[3] Yehui Sun, "Subway window to buy a ticket of the queuing system simulation," *China Water Transport (second half)*, pp.195-197, February 2008.

[4] Zhongkai Wu, "HarBin's station ticket window allocation simulation," *Railway Transport and Economy*, pp.50-53, May 2012.

[5] Kangzhou Wang, Na Li, Zhibin Jiang, "Queuing system with impatient customers: A review," Service: pp.82 – 87, 2010.

[6] Susan H. Xu, Long Gao, Jihong Ou, "Service Performance Analysis and Improvement for a Ticket Queue with Balking Customers," *Management Science*, vol. 53, no. 6 , pp.971-990, June 2007.

[7] Jin Li, "Vehicle routing problem with time windows for reducing fuel consumption," *Journal of Computers*, vol.7, no.12, pp.3020-3027,2012.

[8] Jin Li, Peihua Fu, "A label correcting algorithm for dynamic tourist trip planning," *Journal of Software*, vol.7, no.12, pp.2899-2905, 2012.

[9] Jingwen Huang, Hongguang Li," Process Goose Queue Methodologies with Applications in Plant-wide Process Optimization," *Journal of Computers*, vol.7, no.10, pp.2462-2470, 2012.

[10] Hui Zeng, "Efficient Graduate Employment Serving System based on Queuing Theory," *Journal of Computers*, vol.7, no.9, pp.2176-2183, 2012.

[11] Lu Yu, Xi Zhang, "Assisted Decision-making for Incoming Passenger Flow Management at Urban Rail Transit Hub Stations," *Logistics Technology*, pp.135-138, September 2011.

[12] Yafang Zhao, "Research on Simulation Evaluation of Ticket Vending Equipment's Layout and Configuration in Railway Passenger Station," In: *Beijing Jiaotong University*, 2010.

[13] Hongxu Li, Haiying Li, Xiao Fan, Xinyue Xu, "Anylogic-based simulation analysis and evaluation of subway stations assemble capacity," *Railway Computer Application*, vol.21, pp.48 -50, 2012.

[14] Hong Cao, JiuZhou Wang, JianXin Li, "Application case of traffic simulation in metro engineering design," *China Investigation & Design*, pp.66-69, 2011.

[15] Yanqing Xue, Xi Zhang, "Analysis on optimizations of passenger flow organizations in Beijing South Station based on Anylogic simulation," *Railway Computer Applications*, pp.5-8, February 2012.

[16] Felisa J. Vázquez-Abad, Lourdes Zubieta, "Ghost Simulation Model for the Optimization of an Urban Subway System," *Discrete Event Dynamic Systems*, vol 15, no 3, pp.207–235, September 2005.

[17] Hao Jiang , Wenbin Xu, Tianlu Mao, Chunpeng Li, Shihong Xia, Zhaoqi Wang, "A semantic environment model for crowd simulation in multilayered complex environment," In: *Proceedings of the 16th ACM Symposium on Virtual Reality Software and Technology*, pp:191-198, 2009.

[18] Bernd Heidergott, Felisa J. Vázquez-Abad, "Gradient estimation for a class of systems with bulk services: A problem in public transportation," *ACM Transactions on Modeling and Computer Simulation*, vol 19, no 3, June 2009.

[19] Glenn I. Hawe, Graham Coates, Duncan T. Wilson, Roger S. Crouch, "Agent-based simulation for large-scale emergency response: A survey of usage and implementation," *ACM Computing Surveys*, vol 45, no 1, November 2012.

[20] Bikramjit Banerjee, Landon Kraemer, "Evaluation and comparison of multi-agent based crowd simulation systems," In: *Agents for games and simulations II*, pp: 53-66, 2011.

[21] Yunbin He, Hai Ji "Study on plan Method of Fine profit Ticket window in Passenger Transport Hub," *Traffic & Transportation (Academic Edition)*, pp.63-65, January 2012.