Available online at www.sciencedirect.com
ScienceDirect
Procedia Computer Science 32 (2014) 388 – 396
Procedia Computer Science

The 5th International Conference on Ambient Systems, Networks and Technologies (ANT-2014)

Using Agent-based Simulation Model for Studying Fire Escape Process in Metro Stations

S.M. Lo[a,*], W.L. Wang[a], S.B. Liu[a], J. Ma[b]

[a]*Department of Civil and Architectural Engineering, City University of Hong Kong, 83 Tat Chee Avenue, Kowloon Tong, Hong Kong (SAR), PR China*
[b]*Collge of Logistic and Transportation, Southwest Jiaotong University, PR China*

Abstract

The Hong Kong Metro System has been operating for more than 30 years. With the increase in population, some of the stations are crowded in most time of a day. To facilitate the design and the alteration works for a station, the crowding and passenger movement pattern, especially the escape pattern in case of fire, should be studied. This article illustrated an agent-based people movement model, and a case targeting at the people movement pattern and egress process in a metro station has been studied. The simulation results demonstrate that the model is useful for assisting building designers to evaluate different design alternatives and to support fire safety performance studies.

Keywords: Agent-based Model, People Movement, Evacuation

1. Introduction

Rapid urbanization in recent years has caused extensive influx of people to major cities in many Asia countries. The increase in population has led to an increase in demand for urban traffic. Metro system provides an efficient transportation mean for people in the urban areas. However, the metro system in some cities, such as Hong Kong, has been established for many years. To meet the demand for huge passenger volume, new lines are being constructed and the existing stations are upgraded. In other words, revamping of existing stations with a view to

* Corresponding author. Tel.: +852-2788-7683; fax: +852-2788-7612.
E-mail address: bcsmli@cityu.edu.hk

doi:10.1016/j.procs.2014.05.439

improve the passenger movement efficiency in normal and emergency situations may need to be considered. To facilitate the design and the alteration works for a station, the crowding and passenger movement pattern, especially the escape pattern in case of fire, should be studied. The existing stations have been constructed for many years and the design may not comply with the current fire and building standards. In view of the difficulties in changing the building form, engineers and designers often face difficulties in assuring compliance with all the current standards. In other words, there may have many non-compliance items in the building.

Fire safety performance assessment will then be necessary for the design of the renovation works. It is recognized in Hong Kong's building codes that the prescriptive requirements stipulated in the codes are guidance. If the building designer can demonstrate that the proposed design is able to provide equivalent performance, the Building Authority may approve a non-compliance design. Moreover, performance evaluation can be adopted to assist the designer to select appropriate design alternatives. For a densely populated complex station, the conversion of the layout may be the critical issue and the building designer should spend enormous efforts on establishing an efficient setting. A sophisticated pedestrian flow model can no doubt assist the designer to evaluate the efficiency of the alternative layouts. This article illustrates the use of an agent-based people movement model which can be adopted to evaluate the people movement pattern as well as evacuation pattern. It is useful for assisting building designers to evaluate different design alternatives and to support fire safety performance study.

2. Literature Review for Pedestrian Flow Models

Previously, models of pedestrian movement have generally been considered at macroscopic scale based on simple flow theory [1-2]. Such approach can easily establish the overall crowd density for a region as well as the capacity of a component in the built environment. Other common historical modeling methods for pedestrian flow were simple statistical regression approaches. It used regression to determine the most important factors influencing walking volumes. The other approach adopted fluid-flow analysis, in which pedestrian movement was considered as a fluid moving around obstacles [3-4]. While the said methods can show impact to pedestrian flow from a high-level perspective, they cannot fully incorporate the movement behavior of individual pedestrians.

With the advancement of computer technology, microscopic models of pedestrian movement have recently been developed. In general, the common microscopic approach includes cellular automation (CA) [5-9], agent-based modeling [10-12] and others [13-14]. For CA models, a space is resolved into discrete cells or points. Each pedestrian under simulation will move through the space by occupying the cells and cells occupied will be avoided.

Agent-based modeling technique has been developed on the basis of Craig Reynolds' model (boids) for describing the flocking behavior of birds [15]. For such approach, each individual pedestrian is considered as an agent. The agents will be assigned unique attributes and goals and respond to the environment with respect to the attributes. The simulation may contain a large number of these agents, all acting independently. This makes agent-based modeling ideal for pedestrian flows. CityFlow [16, 17] is an agent based model developed by the authors to simulate the movement pattern of people in a complex setting. It can be modified to simulate the escape process of people in case of fire by assigning the final exits as the destination of all the people in the stations. To further evaluate the effect of fire and smoke on the movement of evacuees, computational fluid dynamics models, such as the Fire Dynamics Simulator, can be adopted to model the fire and smoke spread. Critical points given by the CFD model can be input to CityFlow to model people's movement behavior.

3. Fire Escape in a Metro Station – a Case Study

The Hong Kong Metro System has been operating for more than 30 years. With the increase in patronage, some of the stations may be crowded in most of the time in a day, which brings potential risks to passenger safety in both normal and emergent situations. To facilitate the management of a station, the crowding and passenger movement patterns should be studied. Computer simulation model which can model the passenger movement pattern has been established to evaluate the efficiency of different design alternatives.

3.1. The simulation model—CityFlow

The architecture of the model—CityFlow is outlined in Fig. 1. Three categories of input need to be provided for the simulation model. They are facility space configuration, passenger characteristics and passenger loading. Passenger characteristics include the anthropomorphic dimension; the awareness range and angle of view, walking speed and so on. A "Speed and Density Rule" has been setup in the model based on the empirical data on the speed and density relationship established by Predtechenskii et al [18] and the crowd density and level of service are based on Fruin's works [19]. The model is able to output not only the graphical dynamic demo of the passenger movement process in a station but also the detailed simulation results such as the locomotion time for every individual, the flow rate of a passageway, the bottleneck information within the system.

The model is implemented in two levels: the strategic, tactical level behavior in macroscopic scope and the operational level behavior in microscopic scope. The macroscopic scope mainly deals with the long-term route choice and map navigation tasks to decide a route and obtain a regional perceivable target. The microscopic scope decides the local movement of the agents at every time step. These scopes are executed by the following two modules with communications between them. The route choice and map navigation module identifies the temporary desired regional target of movement, and the agent-based individual movement module uses the target to govern the pedestrian's actual movement, and then calculates the movement direction and distance in the next time step based on detailed environment information and behavioral rules.

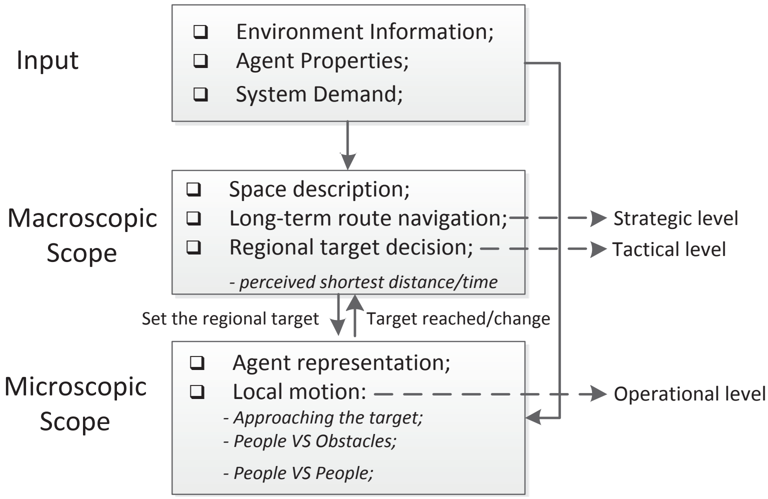

Fig. 1. Architecture of the simulation model—CityFlow

In the model, every passenger can be regarded as a purposeful agent and have an origin and a final destination. It is represented by a circle with a view range, as shown in Fig.2. To make the movement decision at each time step, the following several factors may be taken into consideration. 1) the efficiency of approaching the target, 2) the interaction between the pedestrian and obstacles, 3) the interaction between the pedestrian and other pedestrians, and 4) pedestrian's "Behavior of Inertia"—tend to keep the current walking direction unchanged for saving energy. The route choice behavior focused on 'short-term' decisions based on pre-determined origin-destination matrix. A route-choice model that aims to find the optimal route through the network of the station facilities has been established for each agent [20-21].

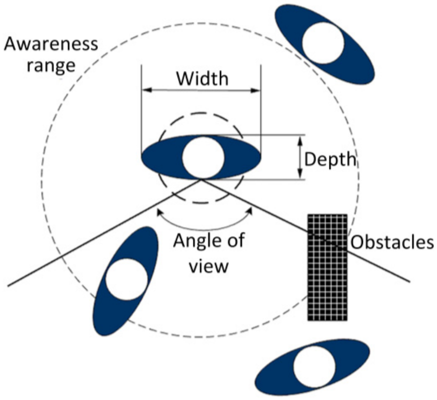

Fig. 2. Characteristics of agents

3.2. The metro station layout information

The station in the case study is located in the central urban area of Hong Kong. It is a three-level underground interchange station, containing two platforms and a concourse (Fig. 3).

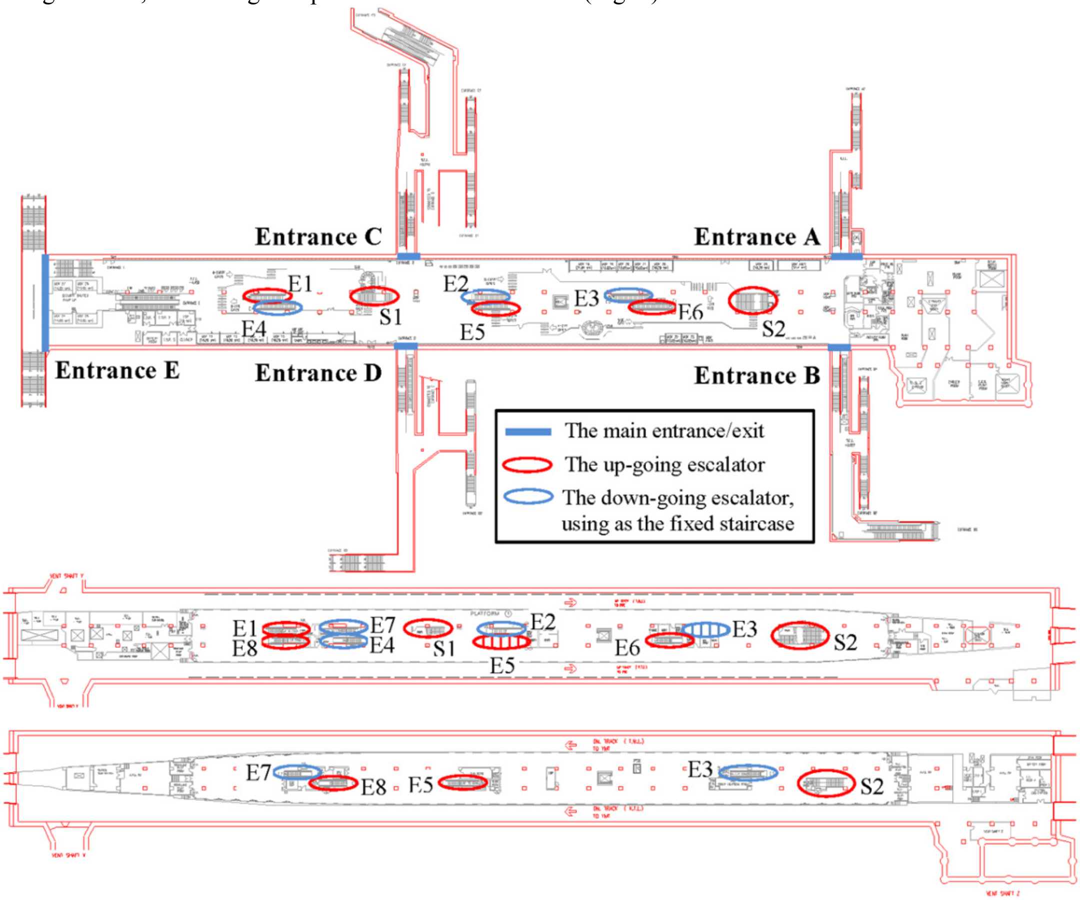

Fig. 3. The metro station layout

There are eight escalators and two stairs linking the different levels of the station, as shown in Table 1. Although directions of escalator will be changed according to the passenger flows at different time of a day, we adopted the most common situation in this study. E7 and E8 link the lower platform and upper platform, one is up-going and the other one is down-going. E3 directly facilitate passengers moving from concourse to lower platform, and E5 runs in the opposite direction. E1, E2, E4 and E6 all link the upper platform and the concourse level of the station. E1 and E6 send alighting passengers to leave the station, and E2 and E4 bring passengers downward to take trains. There are in total ten groups of automatic fate collection gates in concourse level, four groups are entry gates (EG1, EG2, EG3 and EG4), five groups are exit gates (XG1, XG2, XG3, XG4, XG5), and a wide gate (EG5/ XG6) for disabled passengers and passengers with leakages. In case of fire, all the gates should be opened for evacuation, which means passengers can pass the gates from paid area to unpaid area without tickets. The station has five entrances/ exits, and each main entrance has several sub-entrances leading passengers to their destinations. In this fire escape case, main entrance of the station will be treated as the destinations for evacuees.

Table 1. Information about the escalators and staircases in the metro station

Staircase/Escalator	Connecting Level (Lower)	Connecting Level (Higher)	Direction	Emergency Strategy
Escalator 1	Upper platform	Concourse	Up-going	Up-going
Escalator 2	Upper platform	Concourse	Down-going	Stop the operation
Escalator 3	Lower platform	Concourse	Down-going	Stop the operation
Escalator 4	Upper platform	Concourse	Down-going	Stop the operation
Escalator 5	Lower platform	Concourse	Up-going	Up-going
Escalator 6	Upper platform	Concourse	Up-going	Up-going
Escalator 7	Lower platform	Upper platform	Down-going	Stop the operation
Escalator 8	Lower platform	Upper platform	Up-going	Up-going
Stair 1	Upper platform	Concourse	Both directions	Up-going
Stair 2	Lower platform	Concourse	Both directions	Up-going

3.3. Setup of simulation case

Generally, different evacuation strategies should be adopted in case of varied fire types in a metro station [22]. Factors such as station characteristics, fire situation, passenger load, evacuation route should be taken into consideration. In this study, we supposed the fire happened on the lower platform, and all the passengers need to move out of the station. There are some assumptions used in our simulation cases: (1) All the passengers will choose the route with shortest distance in every stage of the evacuation process, taking passengers who are initially on lower platform as an example, they will choose the nearest escalators/stairs first, the nearest gates would then be chosen when reaching the concourse, and so on, indicating preferences in vertical link type (stair or up-going escalator), its extending level (to upper platform or concourse) and gate type (roller gate or wide gate) are not considered; (2) Passengers' free moving speeds used in the simulation were under normal distribution around 1.3m/s, indicating passenger movements in different regions are not considered; (3) Passengers will move orderly and no panic situation happens, and staff in the station will not guide the evacuation; (4) Passengers in each level of the station start escaping as soon as emergency like fire has been confirmed, indicating passengers' response time are not considered.

According to the flow prediction and observation in this station, we made the following passenger number settings in this case. The number of passengers and staff on the lower platform and upper platform are 350 respectively, and number of passengers and staff in the concourse is 700. In terms of the passenger movement between different levels of the station, we used the concept of 'transit line, which usually locates at the end of a vertical link. Taking the passenger moving from lower platform to upper platform through escalator 8 as an example, it will show up at lower end of escalator 8 on upper platform as soon as it disappears from the upper end of escalator 8 on lower platform. By the above mean, we can make the station egress simulation as a whole instead of targeting at single level.

3.4. Simulation results and discussions

The simulation snapshots of passenger escape in the station are shown in Fig. 4, and the corresponding density maps are shown in Fig. 6. From the density maps, we can clearly identify the critical points during the evacuation process, such as vertical links. The dynamic density maps can provide value insight to the designers/ architects. This is useful for assessing the efficiency of the station setting as well as the fire escape routes. It can also provide insight to facility manager to plan the emergency evacuation and rescue strategies.

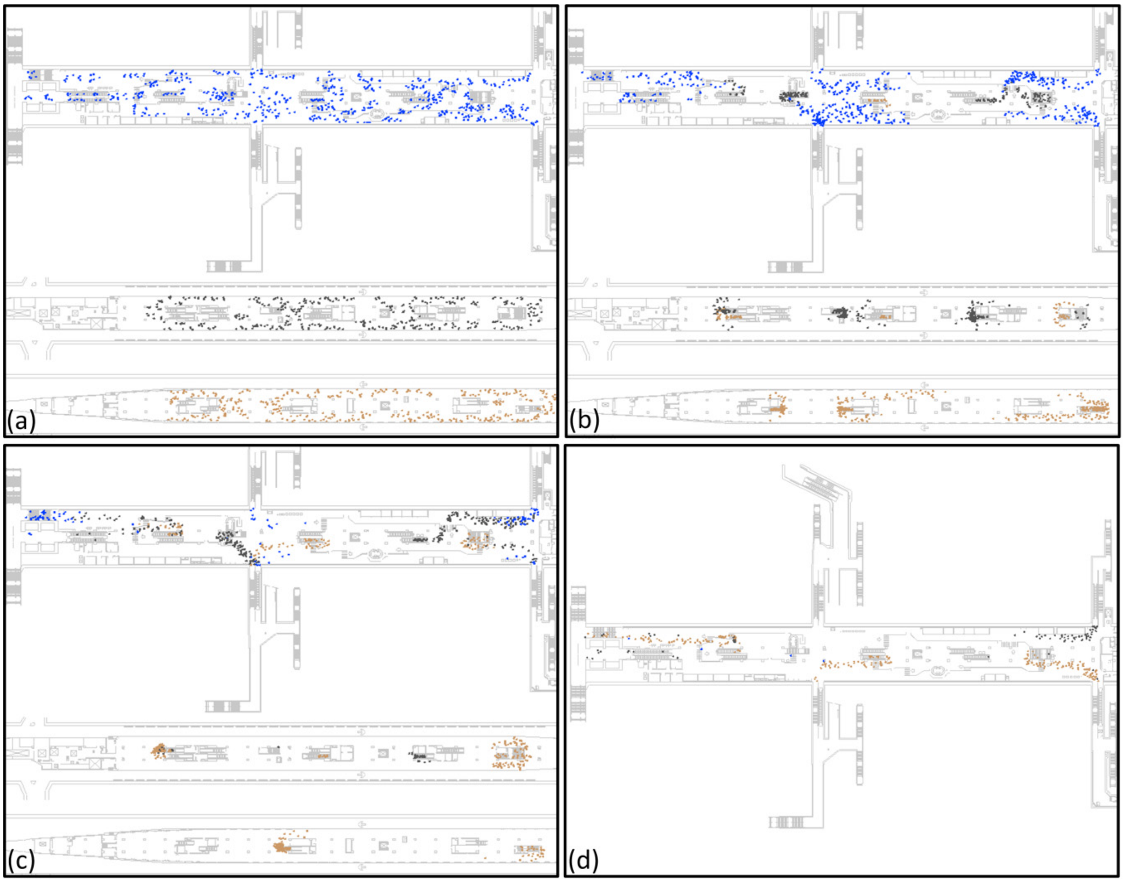

Fig. 4 Passenger distribution inside the metro station during the evacuation process (blue circle indicates the passenger is in the concourse before escaping, gray circle indicates the passenger is in the upper platform before escaping, and dark yellow circle indicates the passenger is in the lower platform before escaping): (a) initial distribution; (b) 20s after escaping; (c) 45s after escaping; (d) 85s after escaping.

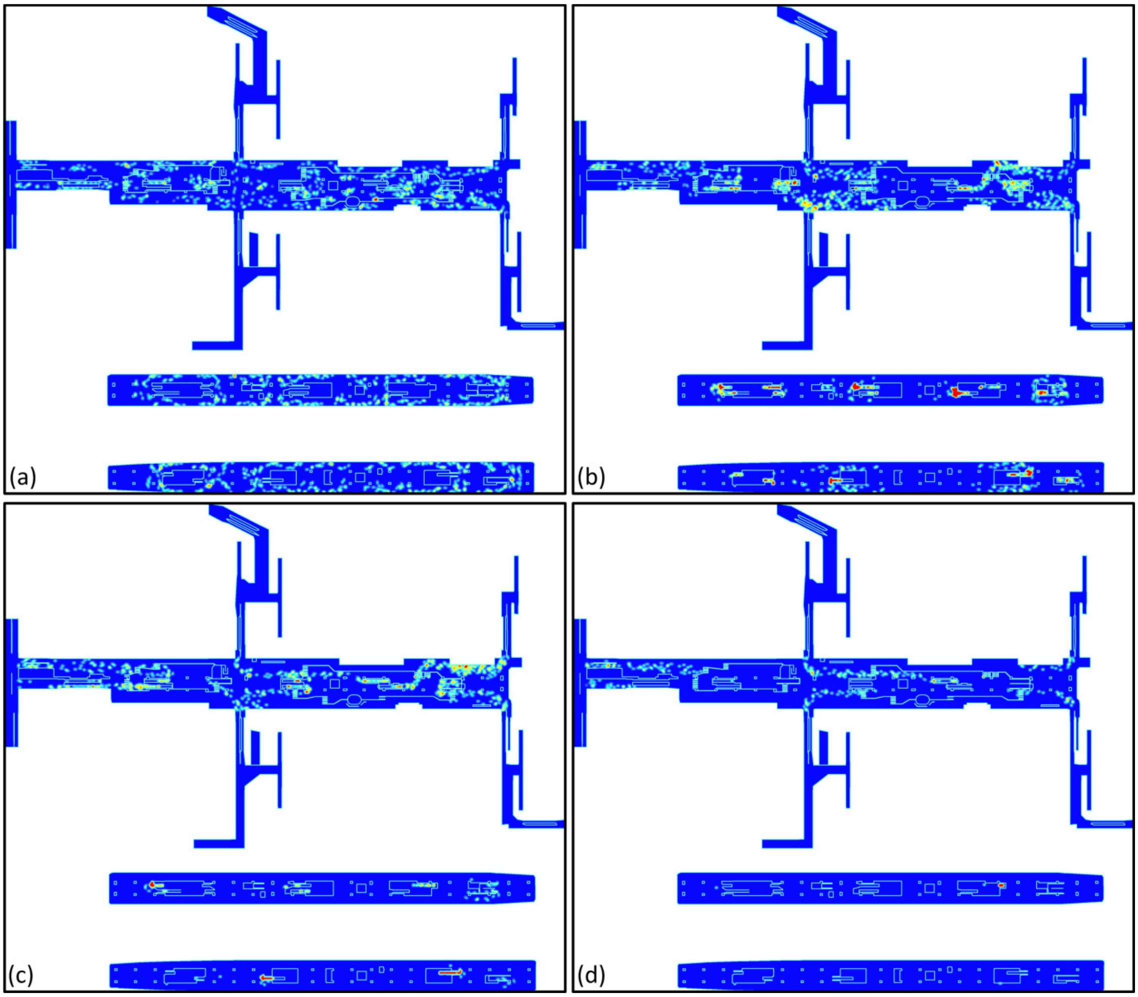

Fig. 5 Density maps of passenger distribution inside the metro station during the evacuation process: (a) initial distribution; (b) 20s after escaping; (c) 45s after escaping; (d) 85s after escaping.

In order to evaluate the passenger escape efficiency, we used the following performance indicators: (1) Total clearance time is calculated when the simulation starts until the last agent arrives at the final target. As shown in Fig. 6, the total clearance time for passengers to reach the main entrance/ exits of the metro station is 163s. More than 95% of the passengers can reach the safe spots within 120s, and around 80% of the passengers can finish the process within 80s after escaping in this simulation case. (2) Travel time is the time interval calculated when simulation starts until an agent arrives at its final target, passengers on different levels of the station and overall values are shown in Table 2.

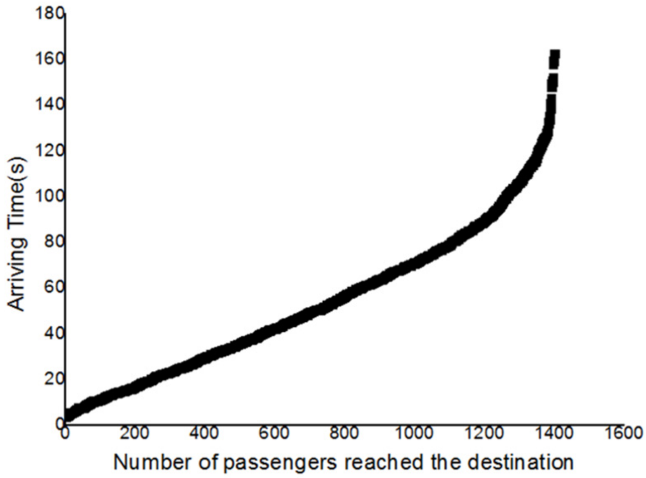

Fig. 6 Passengers' arriving at safe spots by time

Table 2 Passenger escape efficiency in the simulation case

Passengers at different levels of the station	Average Travel Time
Passengers on the lower platform	90.1s
Passengers on the upper platform	63.2s
Passengers in the concourse	25.1s

4. Conclusions

This paper studied the passenger escape in metro stations by means of computer simulation. An agent-based pedestrian movement model—CityFlow has been introduced and a metro station case was simulated. The tool has been demonstrated that it is useful for evaluating the performance of different alteration proposals and to study the fire escape process. In particular, we proposed the concept of 'transit line' to make the station egress as a whole instead of targeting at single level, leading to more practical simulation results. Meanwhile, the dynamic density maps can provide certain implications to the designers/ architects, and valuable insights to facility manager to plan the emergency evacuation and rescue strategies. In future study, we will further develop the model by optimizing the egress route assignment.

Acknowledgements

The work described in this paper was fully supported by a grant from the Research Grant Council, Government of the Hong Kong Administrative Region, China: No. CityU119011. The authors also acknowledge the MTRC, Hong Kong to provide the data for the modeling.

References

1. Togawa K. Study on fire escape based on the observations of multitude currents, Report No. 4, Building Research Institute, Ministry of Construction; 1955.
2. Older SJ. The speed, density and flow of pedestrians on footway in shopping streets, *Traffic Engineering and Control* 1968; **10**(4): 160-163.
3. Henderson LF. On the Fluid Mechanic of Human Crowd Motions, *Transportation Research* 1974; **8**: 509-515.
4. Helbing, D. A fluid-dynamic model for the movement of pedestrians. *Complex Systems* 1992; **6**: 391-415.

5. Gipps PG, and Marksjo B. A Micro-Simulation Model for Pedestrian Flows. *Mathematics and Computers in Simulation* 1985; **27**: 95-105.
6. Blue VJ, and Adler JL. Emergent Fundamental Pedestrian Flows from Cellular Automata Micro-simulation, *Transportation Research Record* 1998; **1644**: 29-36.
7. Blue VJ, and Adler JL. Using Cellular Automata. Micro-simulation to Model Pedestrian Movements. *Proceedings of the 14th International Symposium on Transportation and Traffic Theory*, A. Ceder (ed.) Elsevier Science Ltd; 1999. p. 235-254.
8. Blue VJ, and Adler JL. Cellular Automata Micro-simulation of Bidirectional Pedestrian Flows. *Transportation Research Board* 2000; **1678**: 135-141
9. Lo SM, Fang Z, and Zhi GS. An Evacuation Model: the SGEM Package, *Fire Safety Journal* 2004; **39**: 169-190.
10. Franklin and Graesser, A. Is it an agent, or just a program? A taxonomy for autonomous agents, In: Mueller P, Wooldridge MJ and Jennings NR editors. *Intelligent Agents III*. Springer Verlag; 1997.
11. Schelhorn, T, O'Sullivan D, Haklay M and Thurstain-Goodwin M. *STREETS: an agent-based pedestrian model*. Presented at Computers in Urban Planning and Urban Management; 1999.
12. Willis A, Kukla R, Hine J and Kerridge J. *Developing the Behavioural Rules for an Agent-based Model of Pedestrian Movement*. Presented at the 25th European Transport Congress, Cambridge; 2000.
13. Daamen W. SimPed: a Pedestrian Simulation Tool for Large Pedestrian Areas, *conference proceedings EuroSIW*; 2002.
14. Daamen W. *Modeling Passenger Flows in Public Transport Facilities*. Department Transport & Planning. Delft University of Technology; 2004.
15. Reynolds, Craig. Flocks, herds and schools: A distributed behavioral model. *SIGGRAPH '87: Proceedings of the 14th annual conference on Computer graphics and interactive techniques* 1987. p. 25–34.
16. Yuen JKK, Lee EWM, Lo SM, Yuen RKK. An Intelligence-Based Optimization Model of Passenger Flow in a Transportation Station, *IEEE Transactions on Intelligent Transportation Systems* 2013; **14**(3): 1290-1300.
17. Liu SB, Lo SM, Ma J and Wang WL. An Agent-Based Microscopic Pedestrian Flow Simulation Model for Pedestrian Traffic Problems, *IEEE Transactions on Intelligent Transportation Systems* 2014; in-press.
18. Predtechenskii VM and Milinskii AI. *Planning for foot traffic flow in building*, Moscow, Stroiizdat Publishers; 1969.
19. Fruin J. Designing for Pedestrians: A Level of Service Concept. *Highway research Record* 1971; **355**: 1-15.
20. Bovy PHL and Stern E. Route Choice: Wayfinding in Transport. Networks. *Studies in Operational Regional Science* 1990; **9**.
21. Hoogendoorn SP and Bovy PHL. Pedestrian route-choice and activity scheduling theory and models. *Transportation Research Part B* 2004; **38**: 169-190.
22. Shi CL, Zhong MH, Nong XZ, He L, Shi JH and Feng GG. Modeling and safety strategy of passenger evacuation in a metro station in China. *Safety Science* 2012; **50**: 1319–1332.