

A Planning Model for Evacuation in Building

Hsin-Yun Lee, Hao-Hsi Tseng

Abstract—Previous studies mass evacuation route network does not fully reflect the step-by-step behavior and evacuees make routing decisions. Therefore, they do not work as expected when applied to the evacuation route planning is valid. This article describes where evacuees may have to make a direction to select all areas were identified as guiding points to improve evacuation routes network. This improved route network can be used as a basis for the layout can be used to guide the signs indicate that provides the required evacuation direction. This article also describes that combines simulation and artificial bee colony algorithm to provide the proposed routing solutions, to plan an integrated routing mode. The improved network and the model used is the cinema as a case study to assess the floor. The effectiveness of guidance solution in the total evacuation time is significant by verification.

Keywords—Artificial bee colony, Evacuation, Simulation.

I. INTRODUCTION

CONGESTION is likely to occur during the evacuations of public buildings due to the large number of evacuees. Many researchers focused their efforts on analyzing evacuee behavior in order to minimize the time needed to evacuate public buildings. Nilsson and Johansson investigated the social influence on individuals in a cinema theatre evacuation [1]; Fang et al. proposed a pedestrian waiting-time model for the purpose of alleviating evacuation bottlenecks in stadium evacuation scenarios [2]; Wu et al. applied a control volume model for the evacuation process in a mass rapid transit station [3]; Xudong et al. analyzed behavior during an announced evacuation drill in a retail store [4]; Jiang et al. reviewed and analyzed the regulations for places of public entertainment, such as dance halls [5]. A number of studies have also analyzed and reviewed the evacuation of the World Trade Center Towers on 9/11. Based on the above studies, many scholars analyzing public evacuations have proposed methodologies for, and models of, route networks [6]-[11]. However, the nodes and links in these route networks are usually determined according to the spatial relationship between pathways and rooms. As a result, the route networks cannot reflect the step-by-step behavior and decisions of evacuee movements in the floor. This type of design error reduces the effectiveness of evacuation planning.

In conditions of low visibility, high anxiety, and low environmental familiarity, evacuees need to rely on guidance signs to ensure correct movement behavior. Although many studies have addressed the planning and design of guidance signs [12]-[16], no prior research has attempted to integrate the

location of guidance signs and evacuation route networks in order to find an optimal solution. In rectifying this omission, this paper proposes an improved route network model based on routing guidance. The optimized evacuation routing solution provided by this model can be directly applied to determine the optimal locations of guidance signs. In addition, the proposed model uses an artificial bee colony (ABC) algorithm to provide suggested routing solutions to evacuation planners and building administrators.

II. THE ROUTING MODEL

A. Framework of the Model

Based on the improved route network explained in the previous section, we further propose an integrated routing model. This model integrates an optimization algorithm and simulation. The integration methodology has previously been applied to solving planning problems in many areas [17]-[20]. The framework of the model used in this study is shown in Fig. 1. Users must first input the necessary data, including the number of evacuee groups, the characteristics and location of each group, identified guidance points, available safety exits, parameters of evacuation and the artificial bee colony (ABC) algorithm. With these data, the model is ready to initiate two mechanisms: the ABC algorithm and the simulation. The ABC algorithm controls the movement and behavior of bees (including employed bees, onlookers, and scouts) to establish the routing solutions and their neighborhoods. Next, the routing solutions and their neighborhoods are transferred into the simulation mechanism in order to model the movement of evacuees. The routing solutions and their neighborhoods in this study are simulated in VISWALK, a simulation engine. Using the results of the simulation, we estimate the clearance time of each routing solution and each of their neighborhoods, the clearance time being defined as the time taken to evacuate 95% of the evacuees.

The clearance time obtained from the simulation is automatically delivered to the ABC algorithm and acts as the objective function value for comparing the efficiency of routing solutions and their neighborhoods; in the ABC algorithm, this value is represented as the amount of nectar in a neighborhood. The model iteratively finds routing solutions with a shorter clearance time by searching a neighborhood and assigning scouts to test undiscovered areas.

The optimization process stops upon convergence of the clearance time, that is, when no solution with a shorter clearance time can be obtained after a certain number of cycles. The model then returns the routing solution with the minimum clearance time. The proposed solution offers near-optimal evacuation performance and is therefore a valuable tool for evacuation planners and building administrators.

Hsin-Yun Lee is with the National Ilan University, Taiwan (phone: 886-3-9357400 ext 7542; e-mail: hylee@niu.edu.tw).

Hao-Hsi Tseng is with the National Ilan University, Taiwan (phone: 886-3-9357400 ext 7531; e-mail: hsiyun0520@gmail.com).

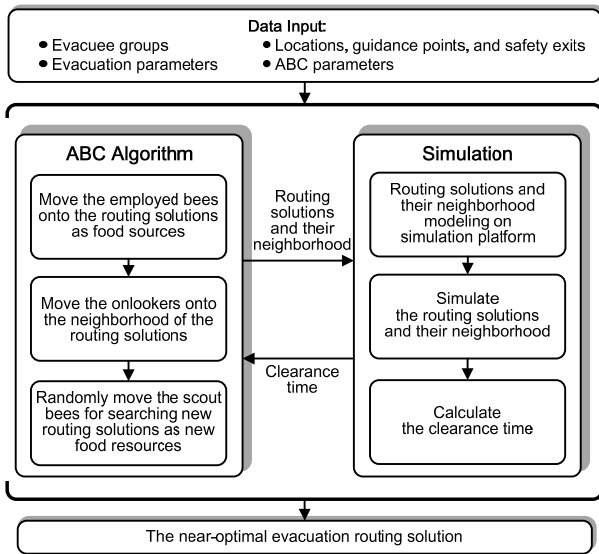


Fig. 1 Framework of the model

B. Applied Artificial Bee Colony Algorithm

In the proposed model, the ABC algorithm is applied to search for the near-optimal routing solution. The ABC algorithm, introduced by Karaboga [21], has been used to solve optimization problems in numerous fields and has been shown to provide outstanding performance [22], [23]. The ABC algorithm is a swarm intelligence algorithm [24] that mimics the foraging behavior of a honey-bee colony within the optimization process. There are three groups of bees in the ABC algorithm: employed bees, onlookers, and scouts. Each employed bee moves to one food source and shares information on this source with onlookers. Then each onlooker selects one of the food sources, using a probability-based assessment of the amount of nectar contained within, then moves to the neighborhood of this selected target in order to search for more food sources. If the bees cannot find any more nectar at the food source or its neighborhood after a certain number of search cycles (a hard limit which is defined within the ABC algorithm), the employed bee will abandon that food source, become a scout, and start to randomly search for a new food source [25].

When the ABC algorithm is applied to evacuation routing optimization, the reciprocal of the clearance time of a routing solution is represented as the amount of nectar within a food source: the shorter the clearance time, the more efficient the routing solution. Both the employed bees in the first cycle and the scouts in each cycle select food sources at random. In other words, the probability of being selected is the same for all available routing solutions. On the other hand, the probability for a food source to be preferred by an onlooker bee depends proportionally on the amount of nectar, $F(\theta)$, at that food source. Therefore, for onlooker bees, the probability (P_i) of selection of the food source located at θ_i can be expressed as [25]:

$$P_i = \frac{F(\theta_i)}{\sum_{k=1}^S F(\theta_k)} \quad (1)$$

where $F(\theta_i)$ is the reciprocal of the clearance time of the i th routing solution (represented here as the amount of nectar at the food source), and S is the number of available routing solutions (i.e. the number of food sources around the hive).

Onlookers watch the dances of employed bees in order to evaluate the amount of nectar at each food source. The amount of nectar at a food source determines the probability that this food source will be selected by onlookers. After an onlooker has selected a food source, it will fly to the neighborhood of that food source. In our routing optimization, the neighborhood of a routing solution is defined by the route choices on the last fork of each evacuee group path. The routing solution for one evacuee group is shown in Fig. 2 and is used to illustrate this optimization method. On the left hand side, the blue route represents a routing solution (terminating at a food source in the ABC algorithm). When an onlooker moves to the neighborhood of this food source, it will view the last routing fork as a neighborhood domain, as represented by the orange routes on the right hand side of the figure. If there are several or dozens of evacuee groups in the network, the neighborhood domains of all the evacuee groups combine to become the entire neighborhood of the routing solution for the evacuee groups. Onlookers will search for routing solutions with the greatest amount of nectar in the neighborhood of each solution in each cycle. Their search will be terminated when the number of cycles reaches a pre-defined limit. Later, the routing solution will be abandoned by the employed bee, and onlookers will no longer move to the routing solution and its neighborhood.

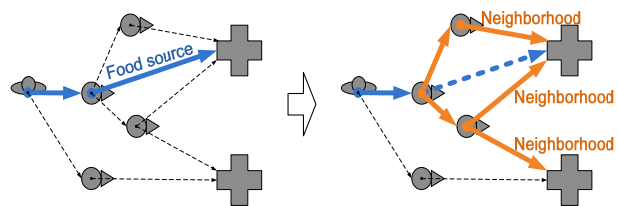


Fig. 2 Routing solution and its neighborhood domain in the ABC algorithm

As a result of searching the neighborhoods of the routing solutions, the bee colony will preserve some routing solutions and abandon others according to the nectar amounts, that is, the level of clearance time. With the increase of search cycles, solutions with less clearance time (i.e. higher nectar amounts) will be preserved, and the solution with the minimum clearance time will gradually be determined.

C. Evacuation Simulation

In the proposed model, we apply a simulation platform in order to estimate the clearance time of each routing solution. To date, a number of methods have been used to measure and model the evacuation process [26]-[29], most commonly through the use of simulation [30]-[33]. Microscopic simulation considers the motion of individuals and the results thus very closely mirror real-world behavior. Several microscopic simulation software packages have been used to simulate evacuations. In contrast to other software, VISWALK

allows the user to rewrite the coordinates in order to assign the guidance points and safety exits of each evacuee group in the file and control the simulation through the interface [34]. Thus, VISWALK was used in this research in order to assess the clearance time of evacuees under different routing solutions.

VISWALK simulates evacuation behavior based on the Social Force Model proposed by Helbing and Molnár [35]. Some previous evacuation simulation models were also based on social force [36]-[38]. The Social Force Model encompasses social, psychological, and physical forces, combining them into a single force that calculates a purely physical acceleration parameter. The forces that influence the motion of an evacuee include the evacuee's own intention to reach his/her destination, the actions of the other evacuees, and obstacles [34]. Therefore, a simulation platform based on the Social Force Model can realistically forecast and estimate human walking behavior.

III. CASE STUDY: THE CINEMA

In this research, we use a floor of a cinema inside a public building as a case study in order to assess the effectiveness of the improved route network and the routing model. On holidays, this floor can contain up to 1258 people, mostly watching movies in the cinemas. In the event of an emergency, the evacuation of people from this theater would prove difficult due to the inherent low visibility and the large crowds of patrons. Evacuees would need guidance in order to reach safety exits safely and quickly. The proposed improved network and routing model can offer a necessary solution to this problem. The evaluation of this evacuation problem can be broken down into three steps: the identification of evacuee groups and guidance points, the search for proper routing solutions, and the assessment of the proposed solution. A detailed explanation of each step is given below:

A. Identification of Evacuee Groups and Guidance Points

As shown in Fig. 3, the floor of this theater consists of six screen rooms (Screens A-F), a fun fair, a food court, as well as some public facilities, such as washrooms and halls. Six safety exits (each marked by a green cross) are available to this floor. In order to build a route network, it is necessary to sort the evacuees into groups. As shown in Fig. 3, each evacuee is not marked individually but is instead assigned to groups based on their location within the theater. Each orange block marked by dotted lines shows the coverage of each group and each orange human icon represents one evacuee group. Based on the visual prominence and efficacy of guidance signs, evacuees within the same evacuee group receive the same evacuation guidance and take the same evacuation route. Consider Screen E as an example: the evacuees in this room are divided into four groups based on the locations where guidance signs could be set up (including walls, ceilings and the back of each seat). Each evacuee group will take a different evacuation route according to the guidance signs within their vision.

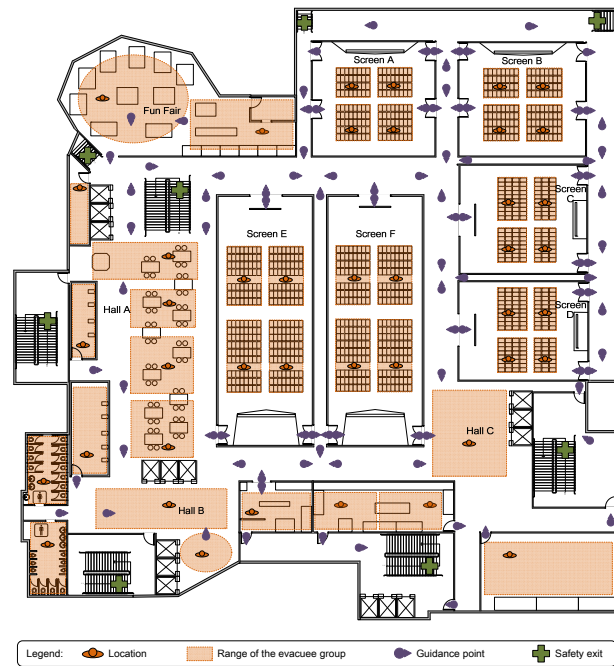


Fig. 3 The layout of evacuee groups, safety exits, and guidance points

Next, the steps proposed earlier are followed in order to find the guidance points on this floor. Evacuee groups must make a routing decision when they move to each guidance point. In Fig. 5 each guidance point is marked by a purple dot with an arrow. The arrow indicates the direction that evacuees will face when passing the area. Most of the guidance points are located at doors or in corridors.

B. Finding the Near-optimal Routing Solution

After identifying the evacuee groups and guidance points, the layout of evacuee groups, safety exits, and guidance points can be inputted into the proposed model. In this model, the evacuation processes are simulated in VISWALK based on the number and characteristics of evacuees. In this case, the number of evacuees is set at 1258 persons, with men and women in equal proportions. 70% of evacuees are considered to be adults, and the remaining 30% are children. The desired speed of evacuation movement varies by gender and age. The desired speed was set according to three random distributions. The first distribution ranges from 3.5 to 5.8 km/hr for adult males, the second ranges from 2.6 to 4.3 km/hr for adult females, and the third ranges from 1.8 to 3.1 km/hr for children.

Another mechanism of the model is the ABC algorithm, which was applied in order to find the near-optimal routing solution with the minimum clearance time. The following parameter settings were used for the algorithm: bee colony size=30, limit=100, maximum search cycle=500. The near-optimal routing solution was found in the 376th search cycle, where the minimum clearance time was 134.6 seconds. Fig. 4 presents the proposed routing solution in the form of the improved network. In this figure, only the guidance points that are used to form a route in the proposed solution are shown. Evacuation planners can set guidance signs at these guidance

points to guide each evacuee group efficiently.

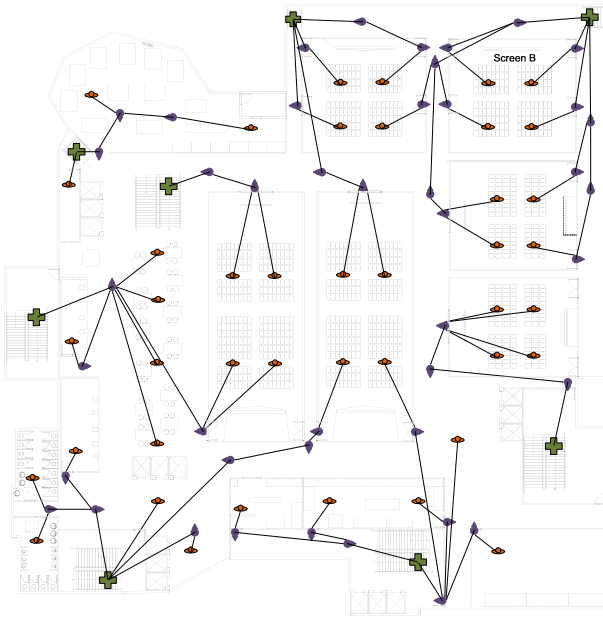


Fig. 4 The proposed routing solution in form of the improved network

C. Assessment of the Proposed Solution

As shown in Fig. 4, under the instructions of the guidance points, evacuee groups may not always take the shortest route to the safety exits. Consider Screen B on the top right of the floor plan, where the four groups of evacuees are directed to use four different doors to leave the room. Two groups are unable to take the shortest path to leave the room, but their movement can ensure that the routing solution avoids the congestion that would result from all of the four groups of evacuees using the same door. To further assess the performance of the guidance points in the improved route network, another simulation of the evacuation is conducted without the guidance points. In this scenario, all of the evacuee groups take the shortest paths to the safety exits. The comparison between evacuation with and without the guidance points is shown in Table I. In this example, we can see that the presence of the guidance points can reduce the clearance time by 9 seconds and the total evacuation time by 22.2 seconds. The effectiveness of the guidance points is also validated by the reduction in the total walking time of all evacuees by 2.7%.

Comparisons	Evacuation with the guidance points	Evacuation without the guidance points
Clearance time (95% evacuees)	134.6 sec	143.6 sec
Total evacuation time (100% evacuees)	156.0 sec	178.2 sec
Total walking time	97896.2 man-sec	100601.8 man-sec

IV. CONCLUSION

Previous evacuation routing models did not consider the direction decisions that evacuees have to make on site. As a

result, the route solutions provided by these models cannot be applied to the layout of guidance signs. In this paper, we propose an improved route network in which all the areas that require evacuees to make direction decisions are identified as guidance points. This improved route network can be applied to planning evacuation routing solutions, which can then be used directly for laying out guidance signs. Furthermore, in some emergency events, some pathways may become blocked or congested. While many guidance points in the derived solutions do not offer the optimal route to evacuation, we believe that it would be prudent for evacuation planners to set up guidance signs at each guidance point in order to support alternative routing solutions for different evacuation scenarios.

In order to minimize total evacuation time, we also proposed an integrated model that would search for the near-optimal routing solution. In this model, VISWALK is applied to forecast the evacuation time of each possible solution. The ABC algorithm is then applied to select better solutions while eliminating bad ones. The effectiveness of our model was evaluated using the case study of a cinema evacuation. Results indicated that the guidance points may guide some evacuees to take routes that are slightly longer in linear distance than the shortest possible routes, but which can effectively ease congestion in crowded areas, ultimately reducing the total evacuation time. The reduction in total evacuation time thus validated the effectiveness of the guidance points.

REFERENCES

- [1] D. Nilsson, and A. Johansson, "Social influence during the initial phase of a fire evacuation — Analysis of evacuation experiments in a cinema theatre," *Fire Saf. J.*, vol. 44, pp.71-79, 2009.
- [2] Z. Fang, Q. Li, Q. Li, L.D. Han, and D. Wang, "A proposed pedestrian waiting-time model for improving space-time use efficiency in stadium evacuation scenarios," *Building and Environ.*, vol. 46, pp.1774-1784, 2011.
- [3] G.Y. Wu, S.W. Chien, and Y.T. Huang, "Modeling the occupant evacuation of the mass rapid transit station using the control volume model," *Building and Environ.*, vol. 45, pp.2280-2288, 2010.
- [4] C. Xudong, Z. Heping, X. Qiyuan, Z. Yong, Z. Hongjiang, and Z. Chenjie, "Study of announced evacuation drill from a retail store," *Building and Environ.*, vol.44, pp.864-870, 2009.
- [5] C. Jianga, W. Li, C. Hub, Y. Xiong, H. Ding, and W.K. Chow, "Emergency evacuation in places for public entertainment in Mainland China," *Building and Environ.*, vol. 44, pp.169-176, 2009.
- [6] M. Ng, and J. Park, "A hybrid bilevel model for the optimal shelter assignment in emergency evacuations," *Computer-aided Civ. Infrastruct. Eng.*, vol. 25, pp.547-556, 2010.
- [7] J.P. Yuan, Z. Fang, Y.C. Wang, S.M. Lo, and P. Wang, "Integrated network approach of evacuation simulation for large complex buildings," *Fire Saf. J.*, vol. 44, pp.266-275, 2009.
- [8] G. Kalafatas, and S. Peeta, "Planning for evacuation: insights from an efficient network design model," *J. Infrastruct. Syst.*, vol. 15, pp.21-30, 2009.
- [9] P. Lin, S.M. Lo, H.C. Huang, and K.K. Yuen, "On the use of multi-stage time-varying quickest time approach for optimization of evacuation planning," *Fire Saf. J.*, vol.43, pp.282-290, 2008.
- [10] T.S. Shen, "Identifying the target spaces for building evacuation," *Building and Environ.*, vol. 41, pp.1600-1606, 2006.
- [11] S.M. Lo, H.C. Huang, P. Wang, and K.K. Yuen, "A game theory based exit selection model for evacuation," *Fire Saf. J.*, vol. 41, pp.364-369, 2006.
- [12] M.C. Zheng, "Time constraints in emergencies affecting the use of information signs in wayfinding behavior," *Procedia Soc. Behav. Sci.*, vol. 35, pp.440-448, 2012.

- [13] C. Chen, Q. Li, S. Kaneko, J. Chen, and X. Cui, "Location optimization algorithm for emergency signs in public facilities and its application to a single-floor supermarket," *Fire Saf. J.*, vol. 44, pp.113-120, 2009.
- [14] C.H. Tang, W.T. Wu, and C.Y. Lin, "Using virtual reality to determine how emergency signs facilitate way-finding," *Appl. Ergon.*, vol. 40, pp.722-730, 2009.
- [15] D.L. Paris, and A. Brazalez, "A new autonomous agent approach for the simulation of pedestrians in urban environments," *Integr. Computer-aided Eng.*, vol. 16, pp.283-297, 2009.
- [16] K. Nassar, and A. Al-Kaisy, "Assessing sign occlusion in buildings using discrete event simulation," *Autom. Constr.*, vol. 17, pp.799-808, 2008.
- [17] H.Y. Lee, "Optimizing schedule for improving the traffic impact of work zone on roads," *Autom. Constr.*, vol. 18, pp.1034-1044, 2009.
- [18] H.Y. Lee, "An integrated model for planning development projects using ACO and construction simulation," *Civ. Eng. Environ. Syst.*, vol. 28, pp.285-300, 2011.
- [19] H.Y. Lee, "Integrating simulation and ant colony optimization to improve the service facility layout in a station," *J. Comput. Civ. Eng.*, vol. 26, pp.259-269, 2012.
- [20] H.Y. Lee, "Renovation scheduling to minimize user impact of a building that remains in operation," *Autom. Constr.*, vol. 22, pp.398-405, 2012.
- [21] D. Karaboga, *An idea based on honey bee swarm for numerical optimization*. Technical Report-TR06. Turkey: Erciyes University, 2005.
- [22] W.Y. Szeto, Y. Wu, and S.C. Ho, "An artificial bee colony algorithm for the capacitated vehicle routing problem," *J. Eur. Oper. Res.*, vol. 215, pp.126-135, 2011.
- [23] S.S.B. Lam, M.L.H.P. Raju, U. Kiran, S. Ch, and P.R. Srivastav, "Automated generation of independent paths and test suite optimization using artificial bee colony," *Procedia Eng.*, vol. 30, pp.191-200, 2012.
- [24] K.C. Lam, X. Ning, and M.C.K. Lam, "Conjoining MMAS to GA to solve construction site layout planning problem," *J. Constr. Eng. Manag.*, vol. 135, pp.1049-1057, 2009.
- [25] D. Karaboga, and B. Basturk, "On the performance of artificial bee colony (ABC) algorithm," *Appl Soft Comput*, vol. 8, pp.687-697, 2008.
- [26] W.K. Chow, "Waiting time' for evacuation in crowded areas," *Building and Environ.*, vol. 42, pp.3757-3761, 2007.
- [27] D. Nilsson, M. Johansson, and H. Frantzich, "Evacuation experiment in a road tunnel: a study of human behaviour and technical installations," *Fire Saf. J.*, vol.44, pp.458-468, 2009.
- [28] V. Papinigis, E. Geda, and K. Lukošius, "Design of people evacuation from rooms and buildings," *J. Civ. Eng. Manag.*, vol. 16, pp.131-139, 2010.
- [29] M. Liu, and S.M. Lo, "The quantitative investigation on people's pre-evacuation behavior under fire," *Autom. Constr.*, vol.20, pp.620-628, 2011.
- [30] L.Z. Yang, D.L. Zhao, J. Li, and T.Y. Fang, "Simulation of the kin behavior in building occupant evacuation based on cellular automaton," *Building and Environ.*, vol. 40, pp.411-415, 2005.
- [31] T.S. Shen, "ESM: a building evacuation simulation model," *Building and Environ.*, vol. 40, pp.671-680, 2005.
- [32] J. Shi, A. Ren, and C. Chen, "Agent-based evacuation model of large public buildings under fire conditions," *Autom. Constr.*, vol. 18, pp.338-347, 2009.
- [33] F. Tang, and A. Ren, "GIS-based 3D evacuation simulation for indoor fire," *Building and Environ.*, vol. 49, pp.193-202, 2012.
- [34] Planung Transport Verkehr AG. *VISSIM 5.40-01 - User Manual*. Germany: PTV, 2011.
- [35] D. Helbing, and P. Molnár, "Social force model for pedestrian dynamics," *Phys. Rev. E*, vol. 51, pp.4282-4286, 1995.
- [36] S. Heliövaara, T. Korhonen, S. Hostikka, and H. Ehtamo, "Counterflow model for agent-based simulation of crowd dynamics," *Building and Environ.*, vol. 48, pp.89-100, 2012.
- [37] Z. Xiaoping, Z. Tingkuan, and L. Mengting, "Modeling crowd evacuation of a building based on seven methodological approaches," *Building and Environ.*, vol. 44, pp.437-445, 2009.
- [38] W.G. Song, Y.F. Yu, B.H. Wang, and W.C. Fan, "Evacuation behaviors at exit in CA model with force essentials: a comparison with social force model," *Phys. A*, vol. 371, pp.658-666, 2006.