Journal of Electrical Engineering 5 (2017) 275-287
doi: 10.17265/2328-2223/2017.06.001

Evaluation of the Behavior of Evacuees on Dynamic Floor Condition by Using Multi-agent Simulation

Keita Sugiura[1], Masahiro Arakawa[2] and Naoto Yokoi[1]

1. Graduate School of Engineering, Nagoya Institute of Technology, Nagoya, Aichi 466-8555, Japan

2. Department of Architecture, Design, Civil Engineering and Industrial Management Engineering, Graduate School of Engineering, Nagoya Institute of Technology, Nagoya, Aichi 466-8555, Japan

Abstract: The prediction of the behavior of people in a disaster has a useful role to play in the design of urban structures such as department stores, schools, and office buildings. We focus on using emergency exit signs to effectively guide the evacuation of people on a floor with a dynamically changing layout. A multi-agent simulation is developed to simulate the behavior of evacuees on a floor. A mathematical model is constructed to obtain optimal sign locations to efficiently assist evacuation under the condition that obstacles are dynamically generated on the floor. The optimal sign locations are calculated by the mathematical model. Then, the developed simulation is performed to evaluate the effectiveness of the emergency exit signs and the behavior of evacuees on simple layout models using the calculated optimal sign locations.

Key words: Multi-agent simulation, emergency exit sign system, dynamically changing floor layout, mathematical model, optimal location of exit sign.

1. Background

The prediction of the behavior of people in a disaster has a useful role to play in the design of urban structures such as department stores, schools, office buildings, and so on. However, since it is difficult to investigate the behavior of evacuees in damaged structures using actual structures and disasters, computer simulation is used for this purpose.

Due to the increasing prevalence of large-scale disasters, it is becoming more important to design buildings that limit damage to people and structures in these events. Computer simulation plays an important role in both the prediction of damage caused by a disaster and the proposal of strategies and procedures to avoid harm to people. In real world problems, computer simulation is used to design structures to keep both people and structures safer, as well as to predict the effects of disaster situations [1, 2].

Multi-agent simulation is used to investigate the behavior of individual people and populations, including theoretical decision-making in complex situations. In past studies, simulation has been adopted to model the behavior of people under the following conditions: customers moving in shops [3, 4]; people escaping from a building [5-7]; and passengers moving in a railway station premises (including the station building and the platforms) [8, 9] among others. Many researchers have studied the behavior of people on different floor layouts, the influence of the initial distribution of people, and the effectiveness of deploying people to assist others to escape. These studies focus on evaluating group behavior and the layout of facilities under disaster conditions.

An emergency exit sign is clearly effective in guiding people to exits in disaster situations in buildings. We previously studied the effectiveness of the location of emergency exit signs in this regard [10]. In the previous study, a mathematical model to calculate the optimal locations of emergency exit

Corresponding author: Masahiro Arakawa, Doctor of Engineering, professor, research fields: production systems engineering, optimization algorithm, simulation.

signs is constructed. The time required to evacuate people from a floor can be reduced by installing exit signs at optimal locations and the behavior of people are evaluated by multi-agent simulation. However, in real disaster situations, the layout of a floor is often changed by the occurrence of obstacles in aisles. These changes to the layout of a floor in real disasters are represented in this study by dynamically changing the layout conditions of the modelled floor. Many evacuees struggle to escape timeously from a building when layout conditions are dynamically changed. In past studies, layout conditions changing dynamically were not considered, and the behavior of evacuees was evaluated assuming guaranteed use of aisles.

This study focuses on a method to effectively guide people by using an emergency exit sign system with a floor layout that changes dynamically. A mathematical model is constructed to calculate the optimal locations of the exit signs on a dynamically changing floor. The effectiveness of the locations identified as optimal by the model is evaluated, and the behavior of evacuees is analyzed, using multi-agent simulation.

2. Structure of the System to Support Evacuation

2.1 Characteristics of the Structure

We use multi-agent simulation to evaluate the behavior of evacuees on a dynamically changing floor layout. Since the purpose of this study is to propose a method to rapidly guide evacuees, we propose a system to calculate the optimal locations of the exit signs for a dynamically changing floor layout and to evaluate the behavior of evacuees. Fig. 1 shows a schematic diagram of the structure of the proposed method. The structure consists of two processes: resolution of the mathematical model to calculate the optimal locations of exit signs and evaluation of the behavior of evacuees using multi-agent simulation. To consider dynamic floor layout conditions, different floor map patterns are prepared based on the probability of their generation [11]. Here, the patterns of the maps are created from several obstacles generated dynamically to occur in aisles on the floor. The optimal lamp locations are calculated to minimize the total distance evacuees need to travel to escape on the different maps.

2.2 Evaluation of the Dynamic Conditions of the Floor

In this study, we evaluate the behavior of evacuees under dynamically changing floor layout conditions, and propose a method to effectively allow evacuees in a building to escape. Here, dynamically changing floor layout conditions denotes the generation of obstacles in aisles in several partial floor areas. When there are multiple areas where obstacles are generated on the floor, different patterns of floor layouts, called “maps”, can be generated from combinations of the areas and obstacles. —Fig. 2 shows a sample of the maps. If different areas have different probabilities for the generation of obstacles, we estimate probability for the generation of the maps including the obstacles at different areas on the floor. The mathematical model is constructed to determine the locations of the exit signs, with the intention of minimizing the total travelled distance of evacuees. Probabilities for the generation of different maps are used as weighted coefficient. In addition, total weighted travelled distance of evacuees considering the weighted coefficients is calculated from different maps as an

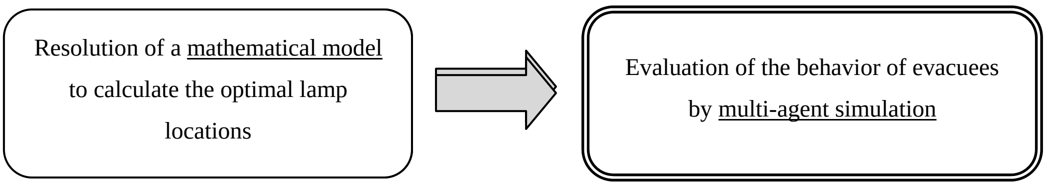


Fig. 1 Schematic diagram of structure of the proposed method.

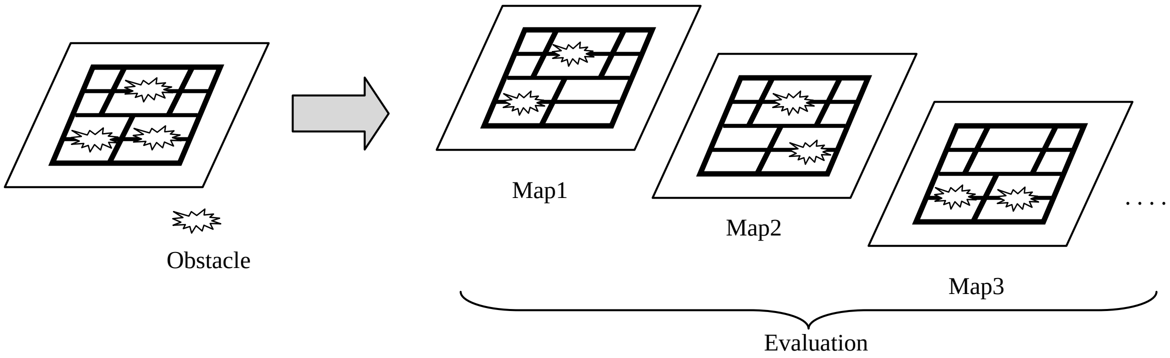


Fig. 2 Sample of maps generated from obstacles on different areas.

objective function. Since the locations of the exit signs calculated from the mathematical model consider the probability of the generation of multiple obstacles, evacuees are expected to escape efficiently under dynamic floor conditions.

3. Multi-agent Simulation

3.1 Simulation Structure

We developed the agent simulation software by using Java language due to Object oriented program language in this study. The software is referred to as the "Agent Simulator" hereafter. The Agent Simulator comprises "Agents" and a "Field". An Agent denotes an object that has the property of an individual person. A Field denotes an object that has the property of a field in which agents can move. The characteristics of these objects are as follows.

(A) Agent

(1) The initial locations and the number of agents can be arbitrarily decided.

(2) An agent collects information regarding the field environment and decides in which direction to move.

(3) An agent does not initially know the exit locations. It moves toward a target in its field of vision.

An agent moves toward targets in the following order of priority:

(i) nearest exit

(ii) emergency exit sign

(iii) nearest agent

When none of these targets is located in the agent's field of vision, the agent continues to move in its original direction. Fig. 3 shows a schematic diagram of the objects regarded as targets. In this study, the agent's field of vision is limited by an angle of 180 degrees, as shown in the figure. The speed and initial positions of the agents are randomly predetermined. In this model, the agents are positioned in an aisle. Two agents are prohibited from overlapping, and must be located at two adjacent grid cells on the floor. Therefore, the distance between different agents has been kept longer than the predetermined cell size on the floor.

Fig. 4 shows a schematic diagram of an agent's movement to avoid an obstacle. When the agent meets the obstacle, it moves along the shape of the obstacle with the shortest length, as shown in the left panel of Fig. 4. Furthermore, when an agent is in the way of another agent, the latter treats the former as an obstacle. Fig. 5 shows a flowchart of an agent's decision-making process. First, the initial locations and speeds in direction are determined for every agent. The agent moves toward targets that it can see in its field of vision. It moves toward an identified target until it arrives at the target. If it recognizes a different target with higher priority than the current one toward which it is moving, it moves toward the new target. When the agent recognizes an exit, it moves directly toward it.

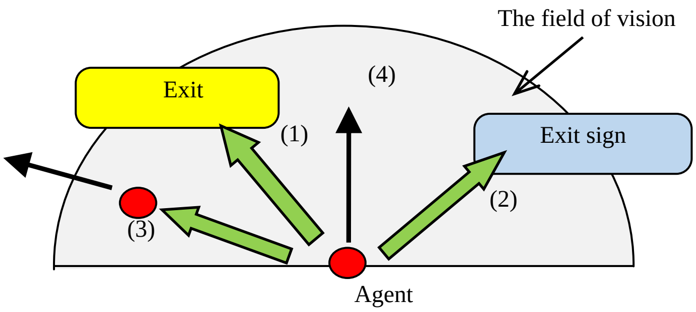


Fig. 3 Diagram of target priority of agents to move.

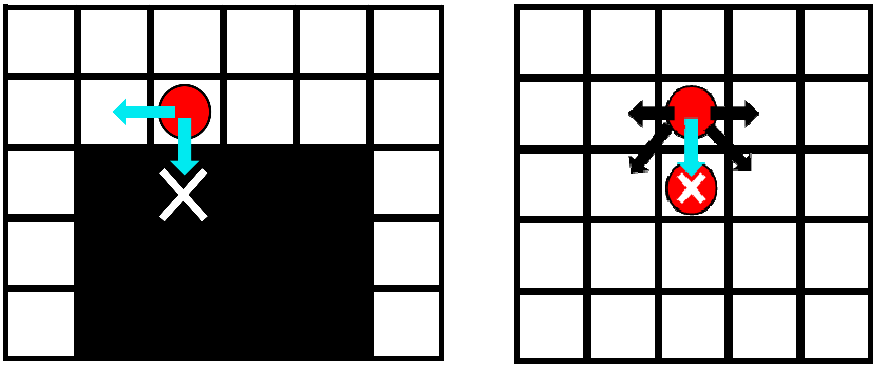


Fig. 4 Example of agent movement when encountering an obstacle.

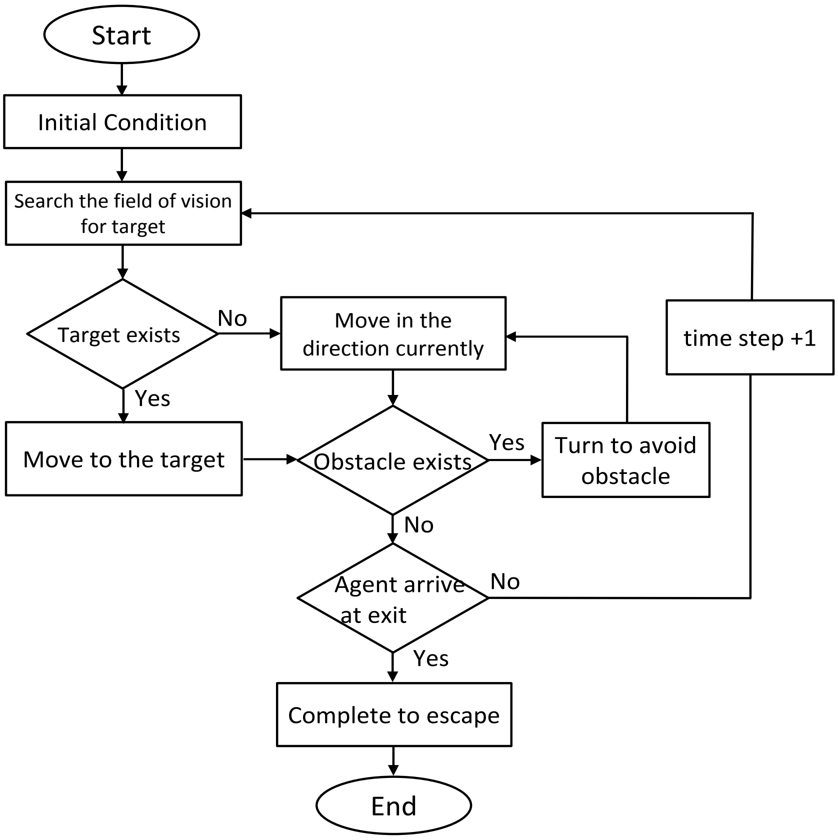


Fig. 5 Flowchart of agent movement on the field.

(B) Field

Fig. 6 shows a sample layout of a floor used in agent simulation. The floor is the field object in the simulation, and agents can move on it. In this figure, the black blocks denote walls and the white blocks denote aisles in which the agents can move. The field object maintains the positions and dynamic variable data for walls, exits, and emergency exit signs as properties of the floor. Grid cells are generated on aisles in the field object. The size of a grid cell is the same as the approximate size of a single real human. The grid cell is used for positioning the agent after avoiding the wall or a different agent. In addition, positions and dynamic variable data for walls, exits, and emergency exit signs are also available in the corresponding grid cells as properties of the floor. An agent retrieves the grid cell properties in its field of vision and evaluates the locations and status of these objects (as exits, walls, and exit signs). Here, when an agent meets an obstacle, it passes alongside the obstacle after its route has been decided by a uniformly distributed random number.

3.2 Simulation Conditions

In the developed simulator, the agent's speed and field of vision can be determined. A single time step in the simulation corresponds to 0.1 s in real time. As for each agent, the object information is collected from its field of vision at each time step. Table 1 lists the parameters for the agent speed and field of vision used in the simulation.

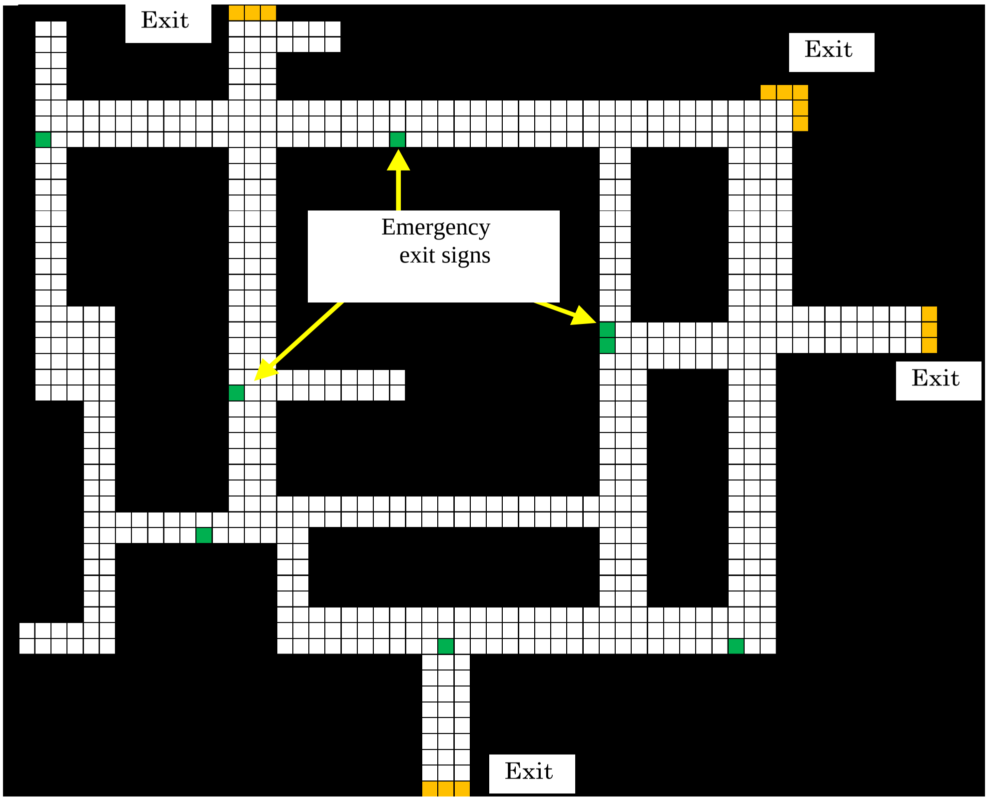


Fig. 6 Sample of the layout of the field object.

Table 1 Basic parameters for agent simulation.

Agent speed	1.0 m/s
Agent field of vision radius	20 m
Grid size in field aisles	1 m/grid

4. Emergency Exit Sign System

4.1 System Characteristics

In this section, to effectively guide people to exits, we focus on emergency exit signs and construct a mathematical model to calculate the optimal locations of the exit signs on the floor. The locations of the exit signs must satisfy the Fire Service Act in Japan [12]. We consider guidance effective when all signs are positioned such that an agent can recognize one or more signs from an arbitrary location. According to this condition, we construct a model to position the signs as follows:

(1) An agent directly moves to the nearest exit when it recognizes an exit.

(2) An agent moves to the nearest exit sign when there are multiple signs in its field of vision.

(3) When an obstacle is located between an exit sign and agent, the agent cannot recognize the sign.

(4) An emergency exit sign indicates the direction to the nearest exit from the sign.

Fig. 7 shows a schematic diagram of the pattern of agent movement and the relationships between the agent, emergency exit sign, and exit. An agent moves to the exit sign when the agent recognizes the sign and the exit is located out of the field of his vision. Therefore, the agent can arrive at the nearest exit.

(5) An emergency lamp is an “A” class emergency lamp that satisfies the Fire Service Act in Japan.

4.2 Mathematical Model for Calculating Optimal Locations of Emergency Exit Signs

A mathematical model is constructed to determine the optimal locations of emergency exit signs from the characteristics of the sign. A set of candidate agent locations on the floor is denoted by $H = \{1, 2, \ldots, h\}$, the set of candidate exit sign locations is denoted by $I = \{1, 2, \ldots, i\}$, and the set of exit locations is denoted by $J = \{1, 2, \ldots, j\}$. Maps including different floor layouts are introduced to facilitate consideration of dynamic floor layout conditions. The set of maps is denoted by $G = \{1, 2, \ldots, g\}$. The maps are generated from combinations of locations of obstacles in advance. Using these sets, a mathematical model to calculate the locations of the lamps is constructed as follows:

Parameters:

d_{ghi}: distance between agent h and emergency exit sign i at map g;

d_{gik}: distance between emergency exit sign i and emergency exit sign k at map g;

d_{gij}: distance between emergency exit sign i and exit j at map g;

MAXDISLAMP: maximum distance between emergency exit sign and exit;

MAX2LAMP: maximum distance between different emergency exit signs;

MAXLamp: maximum number of emergency exit signs;

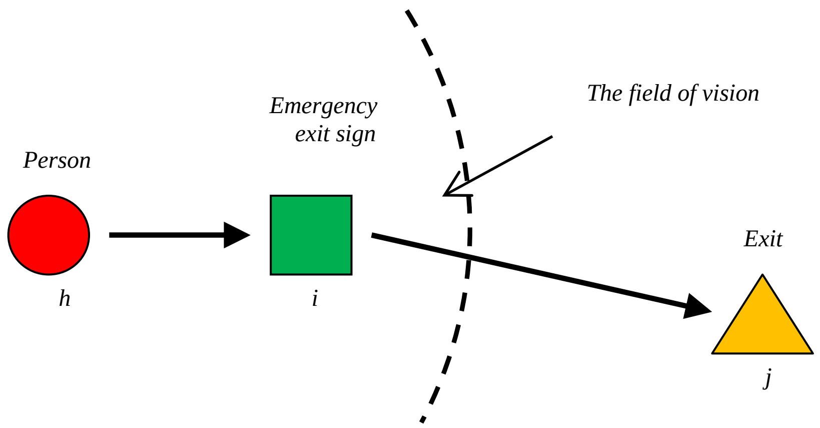


Fig. 7 Schematic diagram of the pattern of agent movement with respect to the relationships between the agent, emergency exit sign, and exit.

P_g: generation probability of map g.

Variables:

x_i: this variable is set to 1 when the exit sign is positioned at location i at all maps; otherwise, it is set to 0;

x_{hi}: this variable is set to 1 when an agent moves from a location in an aisle, h, and the location of an emergency exit sign, i, on all maps; otherwise, it is set to 0;

x_{ij}: this variable is set to 1 when an agent moves from the location of an emergency exit sign, i, to exit j at all maps; otherwise, it is set to 0.

Objective function:

$$Min\ z = \sum_g \sum_h \sum_i P_g d_{ghi} x_{hi} + \sum_g \sum_i \sum_j P_g d_{gij} x_{ij} \tag{1}$$

Subject to:

$$\sum_i x_{hi} = 1 \qquad \forall h \tag{2}$$

$$\sum_i x_i \le MAXLamp \tag{3}$$

$$x_{hi} \le x_i \qquad \forall h, i \tag{4}$$

$$\sum_j x_{ij} = x_i \qquad \forall i \tag{5}$$

$$d_{gij}\, x_{ij} \le MAXDISLAMP \qquad \forall i, j, g \tag{6}$$

$$d_{gik} + M(x_i - 1) + M(x_k - 1) \le MAX2LAMP \qquad \forall i, k, g \tag{7}$$

$$\sum_g P_g = 1 \tag{8}$$

$$d_{gij} + M(1 - x_i) \ge 5.0 \qquad \forall i, j, g \tag{9}$$

Here, M is a big number. Eq. (1) is an objective function that denotes the sum of two types of distance: the total distance between any agent's location and that agent's nearest exit sign, and the total distance between any exit sign and its nearest exit. In the second term, variable x_{ij} denotes the relationship between an exit sign at location i and exit j, as calculated by Eq. (5). The probability of generation of different maps is used for the weighted coefficients of the distances in Eq. (1). Here, the distance between the exit sign and the exit equals the maximum length of the field if there is an obstacle between the exit sign and the exit. Eq. (2) specifies that an agent moves with respect to a single exit sign. Eq. (3) states that the number of exit signs located on the field is less than or equal to the maximum number of exit signs. Eq. (4) specifies that an agent located at any location in an aisle moves to a single exit sign. Eq. (5) states that any exit sign refers to a single exit sign. Eq. (6) specifies that all exit signs are located in an area relative to the exit that satisfies the Fire Service Act of Japan. Eq. (7) specifies that two different exit signs are positioned in an area that satisfies the Fire Service Act. Eq. (8) specifies that sum of probabilities of generation of all maps is equal to 1. Eq. (9) specifies that distance between exit sign and exit is greater than the constant. In this study, the value of the constant is equal to 5.0.

The mathematical model was resolved using the Gurobi Optimizer (October Sky Co. Ltd.).

5. Case Study Using a Simple Floor Layout Model

5.1 Characteristics of the Floor Layout Model

In this section, we evaluate the effectiveness of the optimal locations selected for emergency exit signs using agent simulation. Fig. 8 shows the layout of the model. There are two exits on the floor. The characters A, B, and C denote areas where obstacles are generated and the aisles can be used in the figures. The left figure (Pattern A) denotes a layout including symmetrically located obstacles. The right figure (Pattern B) denotes a layout including asymmetrically located obstacles. In addition, the obstacles are partially placed in small area on the floor in Pattern B.

The simulation results, calculated from two patterns of layouts, are compared to investigate the characteristics of evacuees' behavior under dynamic floor layout conditions. These layouts include the following characteristics:

(1) Four straight aisles cross at right angles and are crossed by two recirculating-type rectangular aisles.

(2) Of the eight ends of the aisles, only two are exits. The others are dead ends.

(3) The exits and aisles are symmetrically structured. It is easy to evaluate the behavior of evacuees under the condition that obstacles are located symmetrically or asymmetrically.

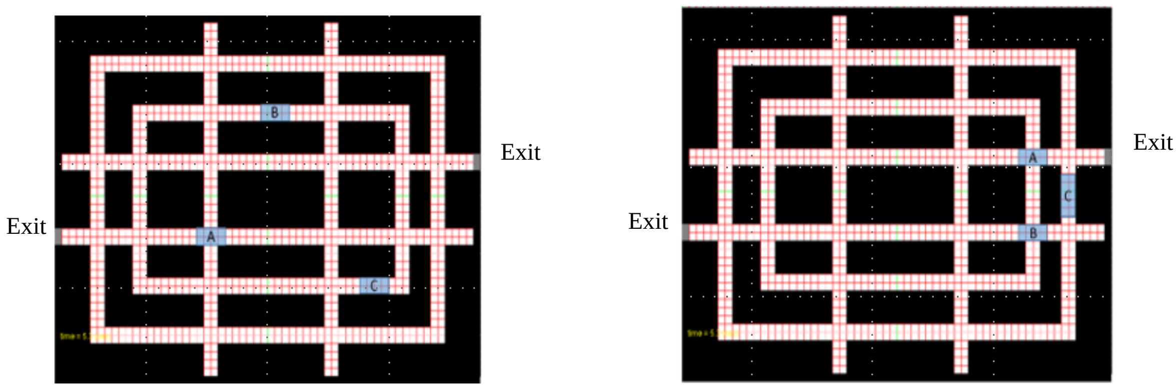
(4) Even if the aisle in a part of the floor is closed, evacuees are still able to move to an exit by avoiding the closed aisle.

(5) On the other hand, since the layout is constructed from horizontal and vertical straight aisles, agents easily collide with other agents moving in a different direction, resulting in agents who cannot escape.

The obstacles are assumed to be generated at Areas A, B, and C with 40%, 30%, and 20% probability, respectively, in both figures. Eight types of maps are generated from the combination of obstacles generated at Areas A, B, and C. Table 2 shows the generation probability of different maps calculated from the generation probability of obstacles at Areas A, B, and C. In this table, 1 denotes the generation of obstacles at the areas in the (A, B, C) column. "The number of trials" denotes the number of trials of simulation for evaluation at different maps.

5.2 Locations of Emergency Exit Signs

Table 3 shows conditions used to analyze the optimal locations of emergency exit signs with respect to the number of emergency exit signs, locations of obstacles, and model for simulation. Figs. 9 and 10 denote the locations of exit signs calculated by the proposed mathematical model for Conditions 6 and 8, respectively. Under the conditions that obstacles are located on the right side on the floor as in Pattern B, Fig. 10 shows many exit signs located near obstacles, requiring people to detour to avoid the obstacles.



(Pattern A: Symmetric layout) (Pattern B: Asymmetric layout)

Fig. 8 Floor layout for numerical experiment.

Table 2 Values used in the generation of the different maps used for simulation.

Map	(A, B, C)	Generation probability	The number of trials	Map	(A, B, C)	Generation probability	The number of trials
0	(1, 1, 1)	33.6%	38	4	(0, 0, 1)	9.6%	10
1	(0, 1, 1)	22.4%	21	5	(0, 1, 0)	5.6%	4
2	(1, 0, 1)	14.4%	14	6	(1, 0, 0)	3.6%	3
3	(1, 1, 0)	8.4%	7	7	(0, 0, 0)	2.4%	3

Table 3 Conditions of locations of emergency exit signs.

Condition	The number of emergency exit signs	Locations of obstacles	Mathematical model considering dynamic floor layout
1	8	Symmetry (Pattern A)	No
2			Yes (the proposed model)
3		Asymmetry (Pattern B)	No
4			Yes (the proposed model)
5	12	Symmetry (Pattern A)	No
6			Yes (the proposed model)
7		Asymmetry (Pattern B)	No
8			Yes (the proposed model)

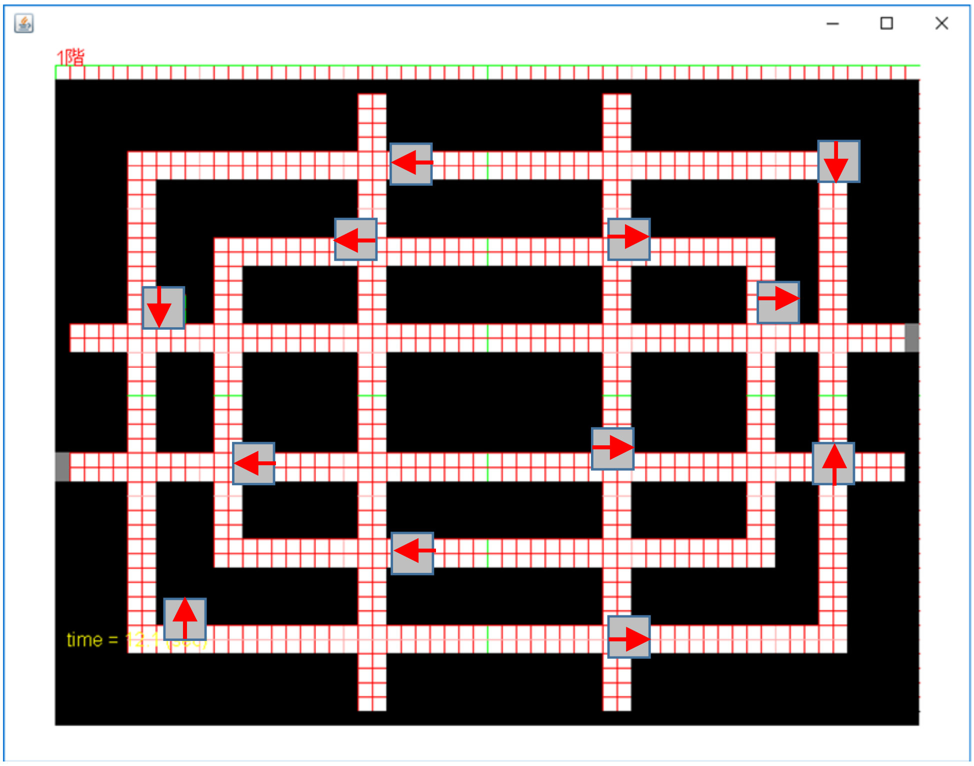


Fig. 9 Locations of the exit signs on the floor of Pattern A under Condition 6: twelve exit signs.

5.3 Evaluation of the Behavior of Agents

In this section, we perform multi-agent simulation to evaluate the behavior of evacuees on dynamic floor layouts including the exit signs, which are optimally located as calculated by the mathematical model. Table 4 lists the simulation parameters. One hundred trials of the simulation were performed and the agent evacuation times were evaluated. Here, the number of trials of the simulation is dependent on the maps according to the generation probability of the maps in Table 2. Evacuees' initial locations on the floor are assigned using uniform random numbers.

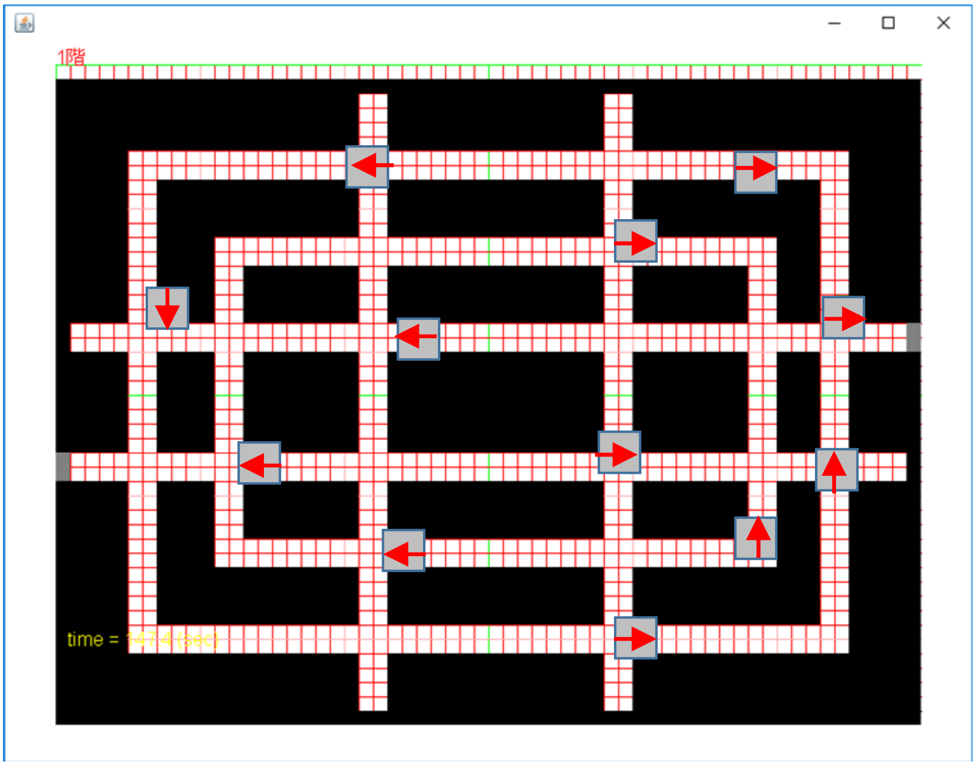


Fig. 10 Locations of the exit signs on the floor of Pattern B under Condition 8: twelve exit signs.

Table 4 Simulation parameters.

The number of trials	100
The number of agents	50
Initial agent positions	Uniform distribution
The number of evacuees or agents	100

Figs. 11 and 12 show the average number of escaped evacuees obtained from one hundred trials. Error bars denote the standard deviation of the number of escaped evacuees. Fig. 11 shows the simulation results obtained under the condition that obstacles are symmetrically located on the floor as in Pattern A. The result obtained under the condition of eight exit signs is compared with that obtained under the condition of twelve exit signs in Fig. 11. The results obtained under Conditions 5 and 6, which are the conditions including twelve exit signs, indicated more escaped evacuees than the other results. In addition, the proposed method could generate more effective exit sign locations from comparison of Conditions 5 and 6. These characteristics suggest that the locations of the exit signs obtained by the mathematical model considering dynamic floor layout are more effective in allowing evacuees to escape when obstacles are symmetrically located on the floor, and when many exit signs are placed on the floor.

Fig. 12 shows the results obtained under the condition that obstacles are asymmetrically placed on the floor as in Pattern B. In addition, the results obtained from different numbers of exit signs are compared in Fig. 12. The number of escaped evacuees is lower across the measured period than the number of escaped evacuees shown in Fig. 11 under all conditions. The result obtained under Condition 3 is far inferior to the result obtained under Condition 4 in Fig. 12. This comparison implies that the proposed mathematical model can effectively determine exit sign locations to facilitate the escape of evacuees.

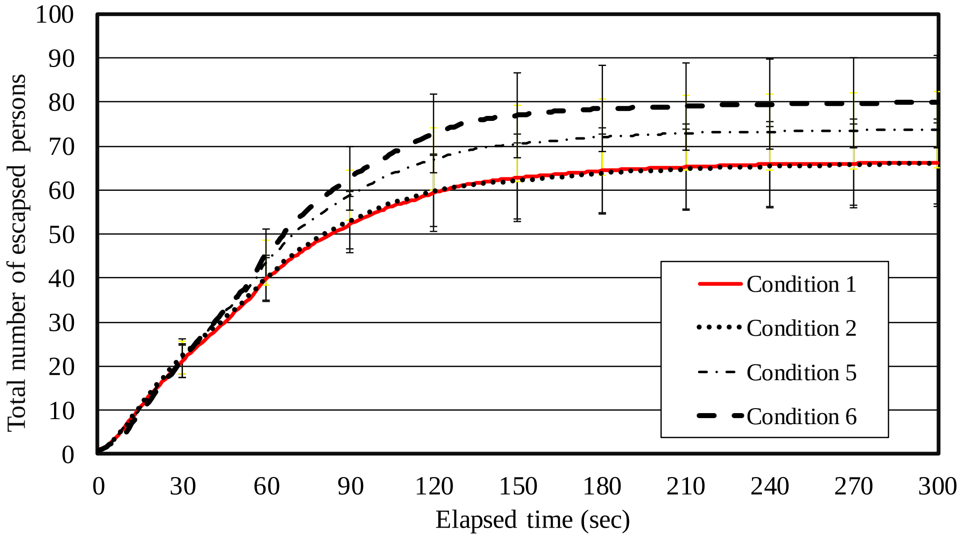


Fig. 11 Comparison of the total number of escaped people calculated by agent simulation using a symmetric floor layout: Pattern A.

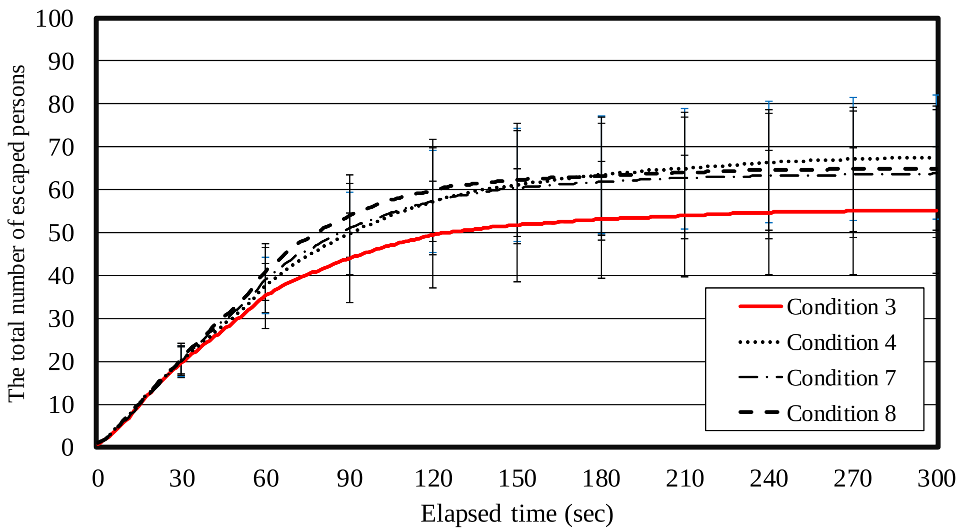


Fig. 12 Comparison of the total number of escaped people calculated by agent simulation using an asymmetric floor layout: Pattern B.

When twelve exit signs are used, the locations of the signs obtained by the mathematical model considering dynamically changing floor layout conditions are superior to the locations obtained by another model. However, there is very little difference in the number of escapees between these models across the measured period. In addition, the difference in escapee numbers using the proposed model remains low across variations in the number of exit signs as shown in Fig. 12. When obstacles are located partially on the floor as Pattern B, many exit signs are located at areas near the obstacles since evacuees move and avoid aisles including the obstacles. Therefore, since many evacuees move by referring to the exit signs, they easily collide at the small area where the obstacles are located and have difficulty moving to the exits. This characteristic of behavior of evacuees causes that the number of escaped evacuees is lower across the measured period on the floor layout of Pattern B under all conditions.

These results show that the proposed mathematical model can generate locations of exit signs to effectively facilitate the escape of evacuees. However, the effective locations and the effective number of exit signs are dependent on the distribution of obstacles on the floor. These characteristics imply that the behavior of evacuees under dynamically changing floor layout conditions requires investigation by multi-agent simulation, even if the optimal locations of exit signs are analyzed by the mathematical model.

6. Conclusions

In this study, we discuss a method to facilitate the rapid escape of evacuees under dynamically changing floor layout conditions. Evacuees are guided to exits by exit signs. A mathematical model is structured to determine the optimal location of emergency exit signs to minimize the total distance travelled by evacuees. Maps are introduced, including different floor layouts dependent on generation probability, to evaluate dynamically changing floor layout conditions. The locations of exit signs calculated by the mathematical model are used for agent simulation to evaluate the behavior of evacuees. The results of agent simulation show that the mathematical model is effective in calculating locations of exit signs to facilitate the rapid escape of evacuees. In addition, agent simulation shows characteristics of the behavior of evacuees under conditions where obstacles are partially located on the floor, and the number of exit signs located on the floor is varied.

In terms of future work, it is recommended that the agent simulation be extended to buildings with multiple floors, to evaluate the behavior of people in more realistic structures. In addition, a new type of emergency exit sign system could be developed to guide agents to exits more efficiently.

Furthermore, in future, the developed simulator will be modified as evacuation simulator for large scale problem as disaster in mountainous region, coastal area, valley area, and so on.

This study was supported by a 2013 Research Grant from the HAYAO NAKAYAMA Foundation for Science, Technology, and Culture.

References

[1] Ohata, D., Takai, N., and Kagami, H. 2007. "Spatial Evaluation of Tsunami Refuge Facilities in the Central Kushiro City: Simulation of Evacuation Behavior from Tsunami Utilizing Multi-agent System Part 2." *Journal of Architecture and Planning (Transactions of AIJ), AIJ* 74 (612): 87-91.

[2] Watanabe, K., and Kondo, A. 2009. "Development of Tsunami Evacuation Simulation Model to Support Community Planning for Tsunami Disaster Mitigation." *Journal of Architecture and Planning (Transactions of AIJ), Architecture Institute of Japan* 74 (637): 627-34 (in Japanese).

[3] Masuda, H., Kikuchi, S., and Arai, T. 2009. "Performance Analysis of Retail Store Layout Using Agent-Based Simulation." *Journal of Japan Industrial Management Association* 60: 128-44.

[4] Kishimoto, A., Takahashi, T., Takahashi, M., Yamada, T., Tsuda, K., and Terano, T. 2009. "An Agent Simulator for Analyzing Consumer Behaviors and Sales Promotion in a Retail Store." *IEICE Technical Report*, AI2008-79, 87-92 (in Japanese).

[5] Pelechano, N., and Badler, N. I. 2006. "Modeling Crowd and Trained Leader Behavior during Building Evacuation." *Computer Graphics and Applications, IEEE* 26 (6): 80-6.

[6] Ohi, F., and Onogi, M. 2008. "A Simulation of Evacuation Dynamics of Pedestrians in Case of Emergency by a 2-Dimensional Cellular Automaton Method." *Transactions of the Operations Research Society of Japan* 51: 94-111 (in Japanese).

[7] Fujioka, M., Ishibashi, K., Kaji, H., and Tsukagoshi, I. 2002. "Assessment for Estimated Evacuees Behavior Using Multi-agent Based Simulation Model." *Journal of Institute of Social Safety Science* 4: 57-63.

[8] Nichinari, K., Kirchner, A., Namazi, A., and Schadschneider, A. 2004. "Extended Floor Field CA Model for Evacuation Dynamics." *IEICE Transactions on Information and Systems* E87-D (3): 726-32.

[9] Satoh, K., Takahashi, T., Yamada, T., and Terano, T. 2009. "Study on Emergent Behaviors of Crowded People in a Station through an Agent-Based Simulation Model." *IPSJ SIG Technical Reports*, 2009-ICS-154(15), 81-86 (in Japanese).

[10] Sugiura, K., and Arakawa, M. 2016. "Evaluation of Behavior of Evacuees on a Floor in a Disaster Situation Using Multi-agent Simulation and Mixed Reality Game: Effectiveness of The Field of Vision and Priority of Referred Objects." *Computer Technology and Application* 7 (5): 227-35.

[11] Aneja, Y. P., and Parlar, M. 1994. "Technical Note-Algorithm for Weber Facility Location in the Presence of Forbidden Region and/or Barriers to Travel." *Transportation Science* 28 (1): 70-6.

[12] Fire and Disaster Management Agency. 1999. Fire Service Act in Japan. http://www.fdma.go.jp/concern/law/kokuji/hen52/52030103020.htm (in Japanese).