Proceedings of the 10th Annual World Conference of the
Society for Industrial and Systems Engineering,
2021 SISE Virtual Conference
September 23-24, 2021

Multi-Agent Evacuation System for Building Fires

Y. Shirai and H. Ono

Department of Management Information Science
Chiba Institute of Technology
Chiba, Japan

Corresponding author's Email: yutaka.shirai@it-chiba.ac.jp

Author Note: Yutaka Shirai is a professor of Department of Management Information Science in Chiba Institute of Technology, is specialized in production engineering (production scheduling, factory planning, shipping plan, etc.). Hiroyuki Ono is an assistant professor of the same department, specializing in environmental management.

Abstract: Japan is well known as a country where earthquakes and typhoon disasters strike frequently. Particularly, damage caused by earthquakes is immense, with secondary damage including fire ensuing immediately. Numerous such fires involve buildings, generating many injuries and deaths. To reduce deaths attributable to fire occurrence, fire outbreak should be noticed at early stages. Subsequently, many evacuation actions can be taken. For this study, an evacuation simulation at building fire at a karaoke bar was conducted using a multi-agent system (MAS). For simulation experiments, after the presence of fire detectors, the locale of the fire outbreak and evacuation actions were verified, the effectiveness of fire detectors and the importance of early notice of fire were clarified.

Keywords: Multi-Agent System (MAS), Building Fires, Evacuation Simulation

1. Introduction

Japan is world famous as a country afflicted by many natural disasters such as earthquakes and typhoons. Particularly, damage by earthquakes is immense. According to a survey of fire and disaster management, although the number of cases of fire outbreak have been decreasing, cases of building fires are still important. About 56% of fire occurrence cases in 2019 were in buildings (Ministry of Internal Affairs and Communications, 2021). The first step of countermeasures against fires in Japan is to provide countermeasures against building fires.

The most important matter for evacuation action after fire occurrence is to escape from the building as quickly as possible. However, it is extremely difficult to move towards an escape door while avoiding fire and smoke. Currently, movement to an escape door is not performed at all for general fire drills conducted in Japan. Practical training for building fires is difficult to accomplish. Therefore, the most effective countermeasure is simulation. A fire state that has not occurred can be verified easily by simulation.

For this study, escape simulation is performed using a Multi-Agent System (MAS) for private karaoke rooms, for which numbers of dead and injured victims are particularly high. Higher rates of death and injured at private-room karaoke venues occur because, in many cases, fires are not noticed along with the location of fire origin, which leads eventually to failure to escape.

In escape simulation experiments, escape actions during building fires under diversified conditions are simulated by combinations of [existence of fire alarm], [place of fire origin], and a [fire condition (speed of fire spread and smoke spread)] in results of simulations. Differences of the numbers of people who are unable to escape are analyzed. The results are compared with those of other cases of fire occurrence to clarify the importance of undertaking escape actions at an earlier stage.

2. Fires in Japan

Because Japan is prone to natural disasters, large scale fires causing many deaths occur more frequently than in other countries. Cases of fire outbreak in 2019 were 37,683. Those in 2018 were 37,981, indicating a slightly reducing trend (Ministry of Internal Affairs and Communications, 2021). This trend is attributable to escape education by fire extinguishing organization,

manualization of escape actions (apparent to everyone), advancement of means to aid escape actions, breakdowns of fire data through improved fire research technologies, increased options for escape action, and selection of escape action suites for fires of different types. For building fires, the usage status of a building should be assessed constantly using information technology as part of the business model.

Of all fires occurring in 2019, fires involving buildings accounted for 56%. Moreover, about 60% of all deaths occurred in buildings (Ministry of Internal Affairs and Communications, 2021). Those data indicate that countermeasures against building fires are the first step to reducing damage from fires. However, building fires differ from fires of other types: they occur in closed areas; also, fires spread and smoke proliferates very quickly. Deaths by carbon monoxide poisoning are particularly numerous.

As for causes of building fires, careless fires from forgetting to turn off a stove account for about 25% of building fires (Ministry of Internal Affairs and Communications, 2021). Unlike escape from an outdoor fire, building fires spread and smoke proliferates during rescue work or when locating a fire origin or during sleeping. As a result, many people fail to escape. Clearly it is best to escape from a building before the entire escape route is covered by fire spread or smoke.

3. Building a Fire Model using Multi-agent System

3.1 Multi-agent System

A Multi-Agent System (MAS) (Sprinivasan and Jain, 2010; Worldbridge, 2009) points to rules related to one's own state and action. It uses objects designated as agents, which are capable of action. With MAS, various events that cannot be expressed in a real society, from crowd difficulties to hazing problems by group action, can be expressed through simulations.

3.2 Simulation software used for this study

For this study, simulation software [artisoc] (Kozo Keikaku Engineering Inc., 2021) was used. Using the software, original simulations can be done by setting various settings when constructing a social model. By mutual action of the agents themselves, these agents can form new events in an unpredictable society. A particular point of effectiveness is that a society model that might not exist in the actual world can be constructed and simulated. Based on the results, a new social model can be proposed. Moreover, in a space model, arrangements of agents and even rules can be set freely, thereby constructing a model effectively.

3.3 Setting of models used for this study

Figure 1 shows the space model (Map) for a private-room karaoke bar used for this study. Two escape ports are provided. The customer (agent) performs escape actions aimed at the escape port closer from the present location. The rooms are (1) – (25), (26) is an office, and (11) – (13) are large rooms. Other rooms are small rooms. An average 3–6 people stay in the big room. An average 1–3 people stay in the small room. Locales of fire occurrence are A, B, and C in the kitchen. The presence of fire detectors and the fire and smoke spreading speeds are set one by one.

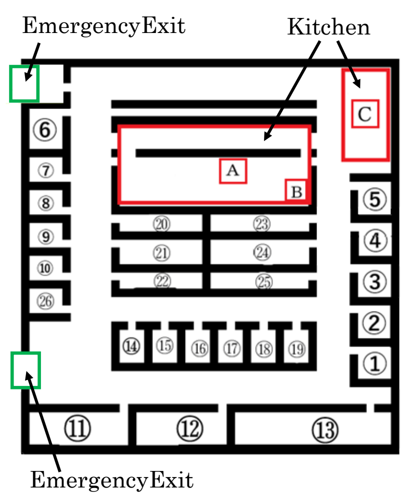

Figure 1. Space model for a private karaoke bar.

3.4 Total flow of simulation and setting of each agent

Figure 2 presents the total flow of simulation of this research. Each agent is set as presented below.

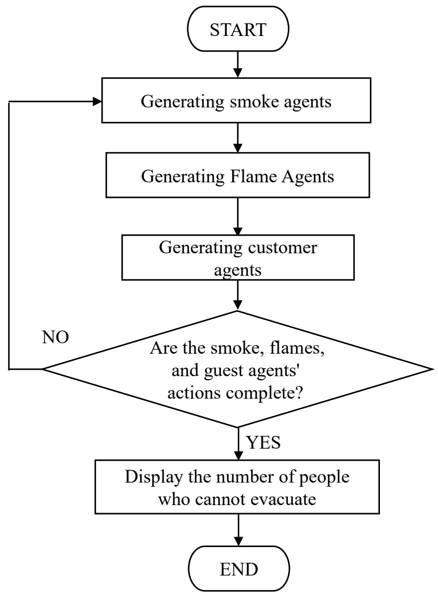

Figure 2. Total flow of the simulation.

Wall agent (Obstacle):

There is no particular rule for a wall agent. However, X–Y coordinates are designed for every wall agent. Other agents (flame, smoke, guest agent) are not allowed to move exceeding the wall agent.

Flame agent:

A flame agent executes the rule determined for every step. First, it checks four cells existing around itself and terminates action if no vacancy exists in any of the four circumjacent masses. It generates a smoke agent (thin smoke) to a vacant cell and then generates a flame agent. Smoke agents are not newly generated if a smoke agent already exists in that cell. A flame agent and smoke agent can exist in the same cell. For fire outbreak of the flame agent, the place of fire occurrence A is depicted in Fig. 3, the place of fire occurrence B in Fig. 4, and the place of fire occurrence C in Fig. 5, whereas ▲ shows a flame agent. The place of fire occurrence A is close to the escape path, fire occurrence B is adjacent to rooms (3) – (5), (24) – (26) across the escape route. Fire outbreak C is such that customers do not pass as the escape route and are from the place that is not adjoining to private rooms. More than two places of fire outbreak are set to realize simulations under various circumstances for private karaoke shops.

[●] : Customer not realizing the fire [●] : Customer started escape action,
[▲] : Flame [×] : Escape port [■] : Wall

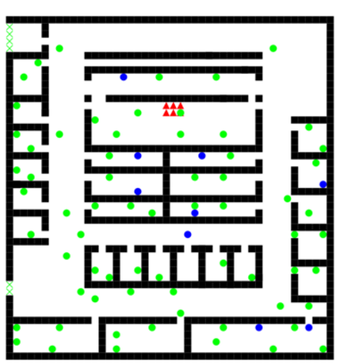

Figure 3. Fire outbreak locale A.

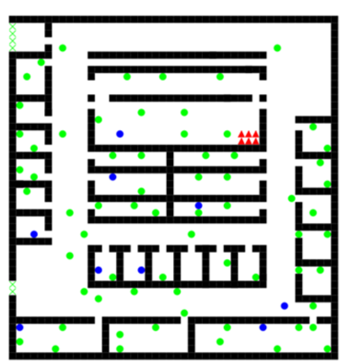

Figure 4. Fire outbreak locale B.

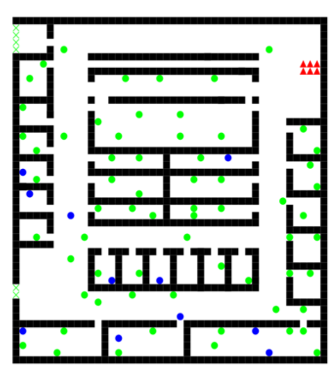

Figure 5. Fire outbreak locale C.

Smoke agent:

A smoke agent is generated from a flame agent. Therefore, it does not exist at beginning of the simulation. Smoke agents of three kinds exist: [Thick smoke], [Normal smoke], and [Thin smoke]. [Thin smoke] is generated by a flame agent as the simulation starts. When it exists in the same cell as a flame agent at the tenth step, it is considered as [Normal smoke]. Furthermore, when it remains at the 20th step, it becomes [thick smoke].

Floor agent:

Floor agent determines to direction in which a guest agent will walk where the potential value is determined. A guest agent walks toward the lower potential direction of the floor agent. It aims at an escape port where the potential value is zero. Therefore, the potential value of floor agents is lowered when approaching the escape location.

Guest agent:

A guest agent ascertains whether another agent or wall agent in the direction of own traveling and uses the ASPF (Agent Simulation of Pedestrian Flow) model (Shohmitsu and Kaneda, 2017) for selecting one of 20 action rules. A guest agent is set such that it realizes fire occurrence with 75% probability and it does not realize it with 25% probability. If no fire detector exists, it cannot start an escape action independently. A guest agent that does not realize fire occurrence is unable to start an escape action without a fire detector. A guest agent that has realized fire occurrence and started escape action changes its color to green [●]. A guest agent that has not realized a fire outbreak has changed its color to blue [●]. When all four circumjacent cells are enclosed by thick smoke, walls, and flame agents, then the color of the guest agent is made black [●], signifying death. When a guest agent reaches an escape location after the escape action, this guest agent is considered to have completed escape. It disappears from the simulation screen. Figure 6 presents one example of a simulation.

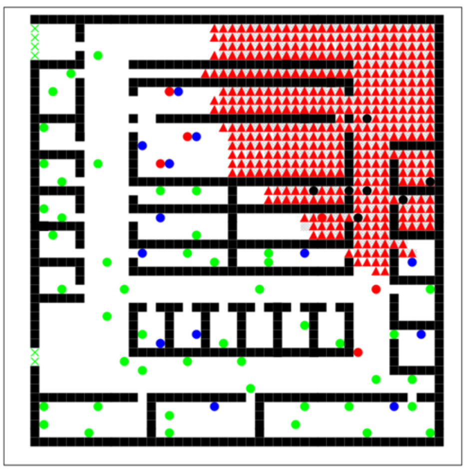

Figure 6. One example of a simulation.

4. Results of Simulation Experiments

4.1 Simulation conditions

The number of guest agents is 84, which is the average number of people staying in private rooms at a karaoke venue. Large rooms (3–6 people) and small rooms (1–3 people) are provided. For a simulation experiment, the presence of a fire detector, the locale of a fire outbreak (A, B, C), and a combination of the following statuses of fire (1) – (3) are set. Each simulation was repeated for ten iterations each to analyze the number of people who failed to escape.

Fire status (1): Rate of spread 1.0, Smoke speed 1.0, Smoke 2 speed 0.7, Smoke 3 speed 0.5
Fire status (2): Rate of spread 0.7, Smoke speed 0.5, Smoke 2 speed 0.3, Smoke 3 speed 0.15
Fire status (3); Rate of spread 0.5, Smoke speed 0.3, Smoke 2 speed 0.1, Smoke 3 speed 0.05

4.2 Simulation results

As simulation results, Table 1 presents the average number of people who were unable to escape under each of the fire conditions. Because independent escape action is extremely difficult in fire status (1), the number of people who were unable to escape exceeds 60 people: more than 70% overall. However, by providing fire detectors, the locales of fire outbreak locations A and C were reduced to less than 10% deaths overall. For fire outbreak location B, even if fire detectors are provided, there are 23.6 people. Those unable to escape are about 30% of all participants because no person staying in a single room (4), (5), (23) and (24) was unable to escape.

When there is no fire detector to show everyone the fire status (2), if compared with fire status (1), the average number of persons unable to escape was five fewer, resulting in 58–61 people. Installation of fire detectors reduced the number of people who were unable to escape to fewer than nine people at any outbreak, i.e., to less than 10% of all persons.

In fire status (3), the fire spread and smoke proliferation occur slowly: a guest agent can escape independently even if no fire detector is provided. If a fire detector is installed, then the average number of people who were unable to escape was lowered to 0–8 people, which is fewer than 10%.

As for the locale of fire outbreak A, a certain distance to an escape route exists, not adjoining a private room, then the average number of people who would be unable to escape is reduced by five people, as compared with other patterns. Fire outbreak locale B is a place adjoining the escape route. Therefore, the average number of people who were unable to escape from all fire accidents is the greatest. Particularly those staying in private rooms (4), (5) (23), and (24) are nearly unable to escape. Regarding fire outbreak location C, a certain distance with an escape route exists. It does not affect the number of people who were unable to escape. From this finding, it might be said that the place of fire outbreak influences the escape rate. However, the fire outbreak locale of is not manipulated, improvement of escape rates depends upon the presence of fire detectors and if each agent has its own escape route.

Furthermore, private rooms (12) – (14) are large. Therefore, the number of people staying in those rooms is 1–3 greater than in other rooms. That fact leads to congestion from private rooms leading to an escape route. Consequently, customers remaining deep inside the private rooms failed to escape frequently. Failure to escape occurred in the private room close to the outbreak location. However, agents staying in private rooms (9) – (19) were able to reach an escape port under all fire conditions. Fire detectors showed strong effectiveness for building fires: apparently they are very effective.

Table 1. Average number of people unable to escape by fire type

Existence of Fire Alarm		Where the Fire Broke Out			Fire Status (1)		Fire Status (2)		Fire Status (3)	
Yes	No	A	B	C	Average Value	Standard Deviation	Average Value	Standard Deviation	Average Value	Standard Deviation
✓		✓			9.7	5.79	6.1	2.73	0.2	0.63
	✓	✓			63.0	2.49	58.5	2.99	60.0	2.62
✓			✓		23.6	4.45	9.0	1.05	8.3	1.83
	✓		✓		64.2	2.35	65.0	2.40	62.6	2.59
✓				✓	8.0	0.00	6.9	0.99	6.5	2.01
	✓			✓	62.0	1.41	61.7	5.38	61.4	3.06

5. Conclusions

In this study of a karaoke venue with private rooms, escape simulations were performed for building fires using MAS. The influence of the number of people who failed to escape was not changed artificially. Escape can be improved by reducing the number of people who do not realize fire occurrence from a response of fire detectors. When no fire detector is provided, a pattern exists by which more than half of the agents failed to realize that a fire outbreak had occurred. When they started their escape action, the building had already been engulfed in flame and smoke agents. This finding clarified that fire detectors are very effective. It seems clear how fatal it is not to notice a fire and fail to escape. For future tasks, diverse conditions should be added. A simulation can be made for approaches corresponding to various building structures.

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ISBN: 97819384962-1-9