Investigation of an Agent-Based Modeling on Crowd Evacuation and Its Application to Real Buildings

Fujio Yamamoto

Department of Information and Computer Sciences, Kanagawa Institute of Technology, 1030 Shimo-ogino, Atsugi-shi, Kanagawa, 243-0292 Japan
yamamoto@ic.kanagawa-it.ac.jp

Abstract. An agent-based modeling and the simulator for evacuation from multistory buildings at the time of outbreak of an earthquake and the fire are presented. The basic theory is that individual agents move in each floor and stair, unless it is filled to capacity per unit area. The simulator can reflect the situation when some destruction occurred in a passage and the stairs in the middle of refuge, because the capacity can be changed dynamically every place. Each agent moves in principle based on local information around oneself. However, as for the cases that the inside of stairs has been clogged up, wide area information equivalent to the broadcast in the hall is conveyed to agents after pre-determined time. Comparative study with the real measurement and simulation was carried out about the refuge time of the fire drill that was performed in a university building of 12 stories.

Keywords: Multi-Agent Systems, Crowd Evacuation, Behavioral Modeling.

1 Introduction

To perform evacuation smoothly when a fire or an earthquake attacked it, both construction of refuge model and the simulation are indispensable. In many cases, it is difficult to determine the most suitable refuge method and the procedure beforehand because they depend on the kind of the disaster or the situation of the place. However, useful information to help real refuge will be provided if such simulations are performed under various assumptions. In addition, knowledge to be provided by simulation can be utilized for a design of new buildings and institutions in future.

A lot of studies on such modeling and simulation were performed so far. Adopted techniques are various likewise. For example, in the case of a train fire [1], in the case of fire of the high-rise building [2], in the case of a fire of indoor stadium [3], and in the case of the earthquake [4], many studies of simulation on evacuation were performed. In addition, there are simulations based on several scenarios considering human psychological condition and group action at the time of the refuge [5,6,7]. The literature [8] presented the simulation for high-rise building designs in consideration of refuge. The comparison of simulation techniques is shown in documents [9] [10].

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Particularly, the literature [10] performs a survey on many related studies in detail. Among a variety of modeling technique, it is said that technique based on the multi agent is suitable for such a refuge modeling in particular [11]. However, the study of modeling to adapt to each building is still insufficient, due to the variety of characteristics of people there and of structures of the building including stairs, corridors and exits. Also, most studies in the past did not compare the simulation results with the data obtained from real refuge.

We made an agent-oriented general-purpose refuge model and tried to apply it to a real building. A way of thinking and the summary of the modeling are shown in the literature [12]. The first good point of our model is that every grid cell of stairs and the corridor can dynamically set the capacity that can contain refugee agents. The movement principle of an agent is simple. It facilitates an application to the structure of a variety of stairs and corridors. We developed a simulator based on this modeling, and we applied it to the evacuation of the buildings of our university. By the comparison to the actual evacuation drill that a large number of students participated in, usefulness and the problems of this simulator were evaluated.

2 Outlines of Modeling and the Simulation

2.1 Agent-Based Modeling for Crowd Evacuation

The summary of refuge modeling and the simulation used here was shown in the literature [12]. The main points are as follows:

High-rise buildings of universities or institutes where many people (about several thousand persons) exist in were targeted for this study. Those buildings are assumed to have laboratories, meeting rooms, lecture rooms, dining rooms, and so on. Most people there are assumed to know the internal structure of the buildings well. At the time of the refuge, elevators are not usable, and they escape from the building by using only plural stairs (the capacities of each stairs are different).

The modeling depends on multi agent technique. Evacuees, emergency services, and unit area of floors and stairs (patches) become agents respectively. Every each floor can set the existing number of people as a parameter. At the initial stage, each person leaves for the stairs of the place that is the nearest to oneself except a specific floor. However, after a refuge start, when agents understood that another stairs of the same floor is not crowded, they can change their target to that stairs. Also the simulator can assign specific usable stairs to evacuees of each floor.

In the middle of refuge, some kind of disorders may occur in stairs and a corridor. The passage capacity at any place can be changed dynamically to reflect it. When refugees who entered the stairs cannot move at all for a long time, such situation is conveyed to evacuees as global information, like the communications using broadcast in the hall or using the cell-phone. Each agent who received such global information can leave for another stair of nearest floor.

2.2 Movement of Agents

In a corridor or stairs, people move to their neighboring cell unless the capacity (maximum allowable number of persons) per unit area is exceeded. Otherwise, they must remain there. The speed to walk a corridor and the stairs can be set as a parameter. The default speed is set to an actual value when a person walked when stairs and a corridor are not congested at all. The default speed is set to an actual speed when a person walked in the case that stairs and a corridor are not congested at all. Due to this movement principle, a rescue crew can climb up to the target floor against the flow that a large number of people evacuate to. This is because rescue services also move according to the rule of the passage capacity mentioned above.

Fig. 1 illustrates the principle of movement mentioned above. Small grids divide stairs and the corridor. $F(C_{ij})$ denotes the maximum allowable number of people in the cell C_{ij}. About the C_{ij}, the set of the agents, which are going to move to an adjacent different cell, is $Pexit(C_{ij})$, and reversely the set of the agents, which are going to enter this cell, is $Penter(C_{ij})$. On the other hand, the set of agents remaining in the cell C_{ij} is $Premain(C_{ij})$. This figure illustrates that whether or not an agent can move to other cell is determined by $F(C_{ij})$.

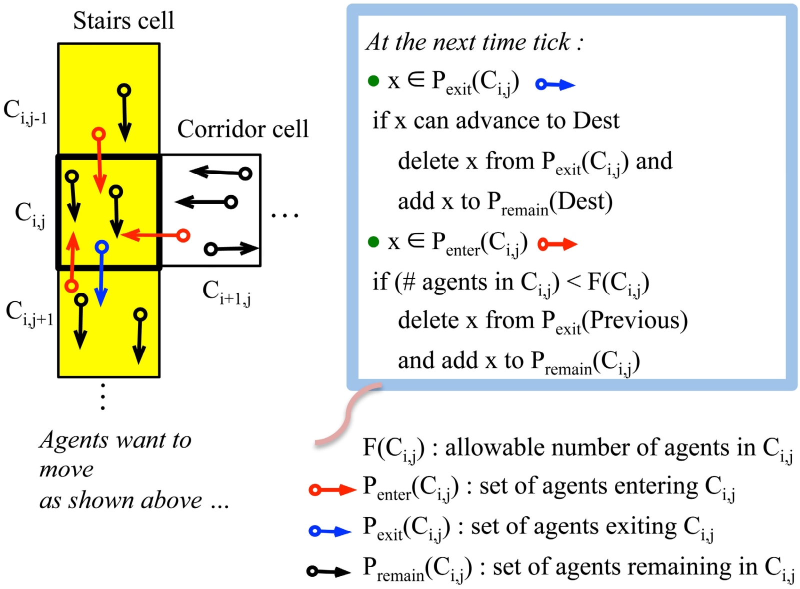


Fig. 1. Method for Agent Movement

3 Applications to University Buildings

3.1 Internal Structure of the Building

The evacuation simulation mentioned above is compared with the data provided in a real evacuation drill, so that in the first the structure of the building is shown in Fig. 2.

It is a 12-story building, in which there are laboratories, lecture rooms and an office on each floor. Usually there exist 300 to 1,800 students and staff. The existence number of people considerably changes depending whether it is an authorized class period or not. Although there are five elevators (including one for emergency), at the time of the refuge of the disaster, they are not used and two flights of stairs (north and south) are usable instead. The width of south stairs is slightly wider than north stairs. Going down the stairs, we reach the first floor, which has two exits. When a large number of people evacuate all at once, stairs and corridors may be clogged up, but also the exit of the first floor may become a bottleneck.

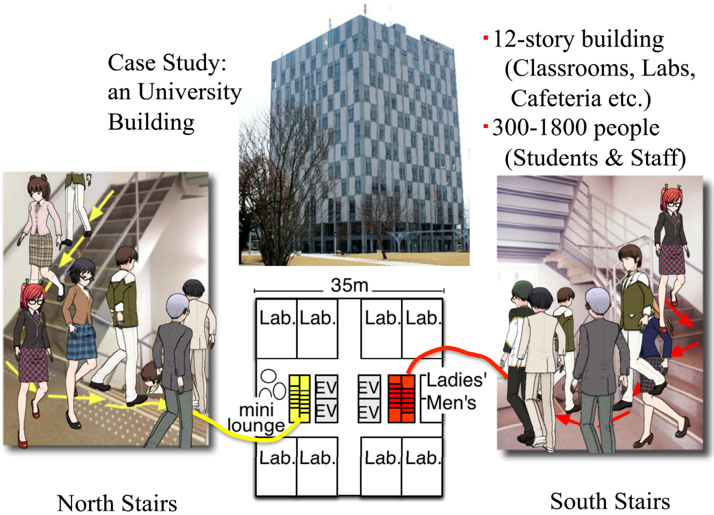


Fig. 2. Internal Structure of the Target Building

3.2 Measurement of an Evacuation Drill

At the time of a real disaster, it is difficult to measure time required for many people evacuating from a building. However, usually most universities carry out evacuation drill at least once a year. That is a good opportunity to measure real evacuation time and related data. Therefore appliances shown in Fig. 3 were prepared. First of all it is necessary to count how many people finally evacuated from a building. Both automatic counters and hand-operated counters were prepared. Using them, measurement was done in two places of exits of the lobby of the first floor. More importantly, we made a plan to record the time at which persons who were appointed as monitor passed through each floor during evacuation. Therefore, NFC (Near Field Communication) tags in which floor information was written were put on the wall of the entrance of each stair. Stairs information and the time are recorded by touching these tags at Android terminal when a monitor refugee passes through that place.

The collection method of the passage time for each stair using the NFC tag is shown in Fig. 4. In the Android terminal, which the monitor refugee has, an application program to read an NFC tag message (the floor number) and to record the time is available. In addition, the application transmits those data to Google Fusion Tables so that all data can be summarized later. The graph of the figure shows the records of five students who went down the north stairs. They were in the eighth floor, the ninth floor, and the tenth floor, and they began evacuation at different time each other. There is a record of five similar students about the south stairs, although it is not included in the figure. Although the refugees were several hundred altogether this time, the detailed action record of these ten refugees, was a valuable record as explained in the following.

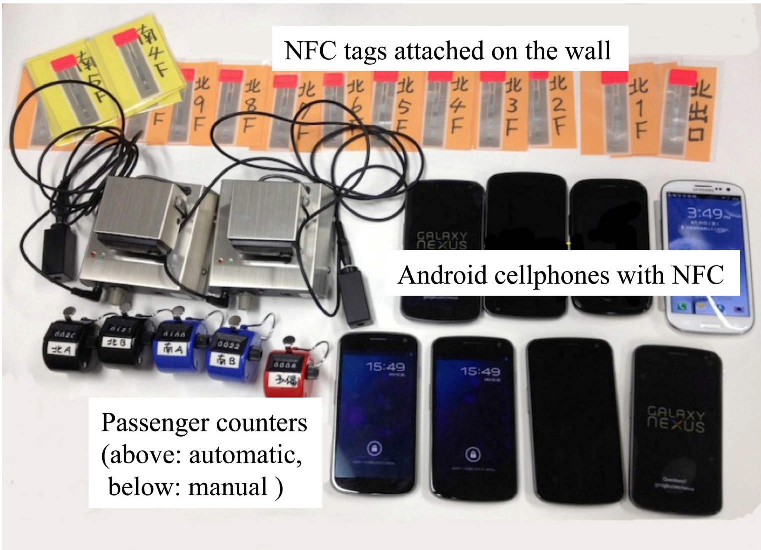


Fig. 3. Appliances for Evacuation Measurement

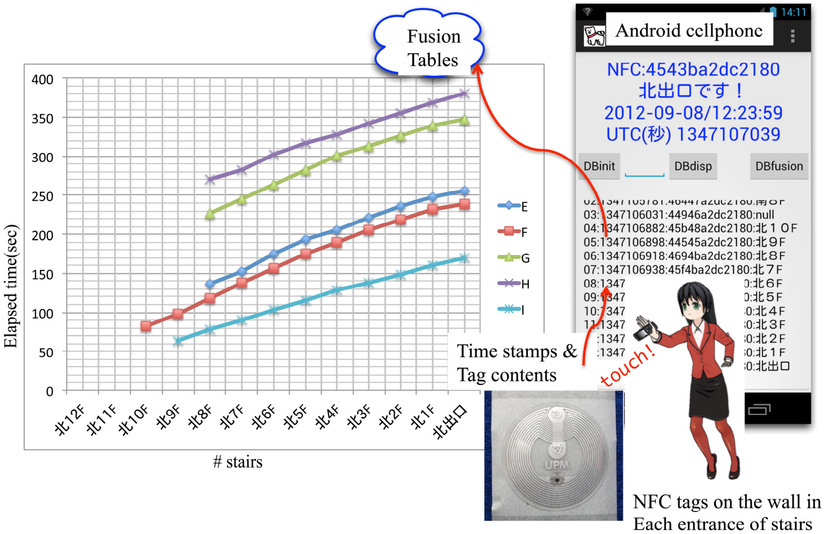


Fig. 4. Evacuation Time Recording Application

3.3 Execution of the Simulation

The typical screenshot of the refuge simulator that we developed is shown in Fig. 5. The back figure shows the situation of simulation of start time, and the front figure shows the later situation. With sliders put on the left side of the screen of the simulator, the setting of various parameters is possible. For example, existing number of people, the capacity of each floor and stairs, and also walking speed are included. There are two flights of stairs on both sides of the figure in lengthwise direction. The capacity of those stairs is set separately. In the upper part of the figure, the elapsed time from the start, the arrival time to be required to emergency services, and the number of holdovers in the building is displayed respectively. In addition, in the right side, the number of the holdovers of each floor is displayed in real time. The enlarged picture of the specific place is shown in the central small window. With this, we can observe current congestion degree near a specific entrance of stairs.

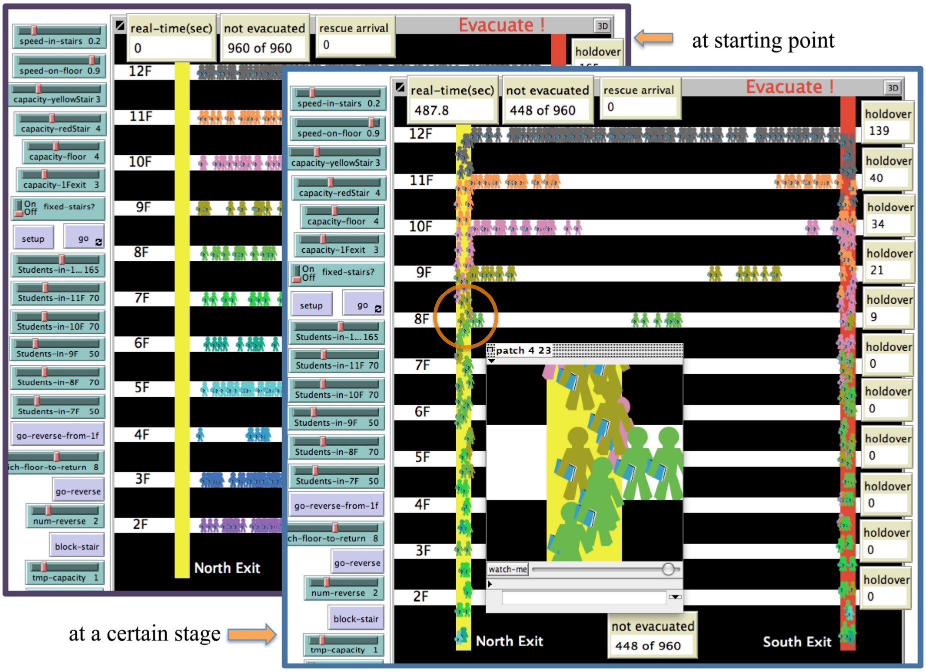
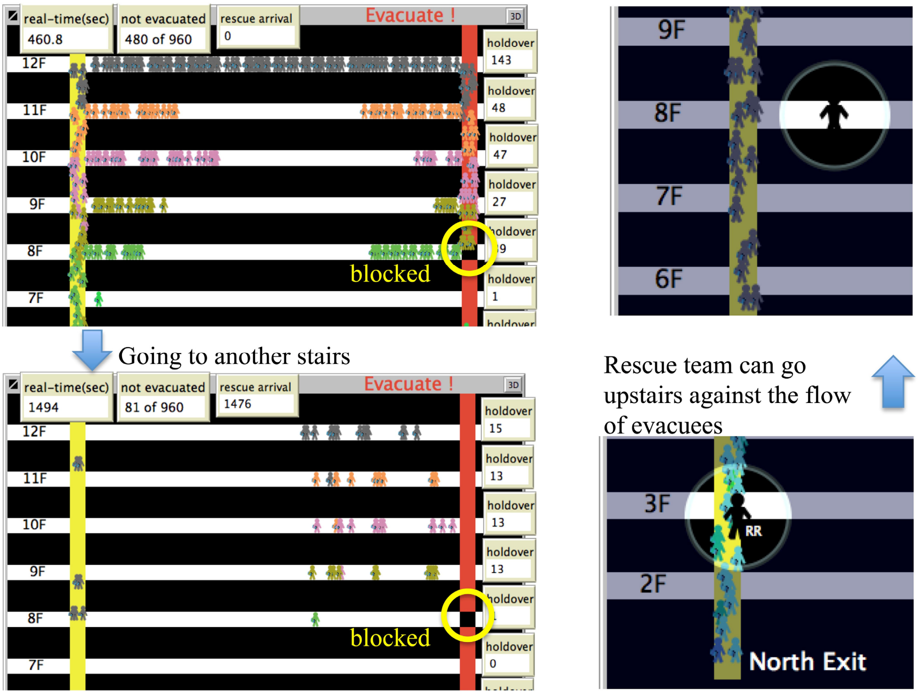


Fig. 5. Overview of the Simulator

On the other hand, Fig.6 explains other functions of this simulator. Fig.6 (1) shows the case that stairs were blocked up. In this example, the right-side stairs were damaged at the eighth floor approximately 460 seconds after a refuge start and was not able to pass. These stairs were blocked out for a while, but information on this situation was conveyed to evacuees in a manner like broadcasting in the hall after pre-determined time. By this information, the evacuees who were shut in stairs are shown to have left for another stairs of nearest floor.

Fig. 6 (2) shows such situation that one rescue crew climbs from the first floor to the eighth floor. Because a large number of evacuees go down, it is not easy for him to climb the stairs against the flow. However, according to "the movement principle of the agent" that is explained in the section 2.2, emergency services can enter the cell at the moment when the existence number of people in that cell decreases lower than the allowable number. This example illustrates such situation that a rescue crew arrives at the eighth floor somehow and then moves to the central place on the eighth floor. Two functions shown above supported a possible phenomenon by real refuge. Namely these contribute to make this simulator practical.



(1)Blocked stairs or corridor (2)Dispatching rescue

Fig. 6. Additional Features of the Simulator

4 Comparisons between Simulation Result and Measurement

In this chapter, an actual value and the simulation result in the time required for the refuge from the building for university described in Chapter 3 are compared. Table 1 shows three cases, namely “No classes”, “Typical case” and “Maximal case”. The number of people existing in each floor from the first floor to the twelfth floor is displayed. This figure shows simulation results about the time required for overall refuge. And in addition, actual measurement result is shown about some cases.

The first case "No Classes" denotes the evacuation drill shown in Section 2.2. The normal class was not carried out on that day, and the guidance of the new school term was carried out instead. The total number of evacuees was 396 and it took 510 seconds (observed time) to finish refuge at all. With this case, a traffic jam was hardly caused in the stairs, mainly because the number of evacuees was fewer than usual. The simulation result was from 426 seconds to 547 seconds, this variation depends on the setting of parameters. With this case, it can be said that the simulation result and the actual measurement were almost equal.

The second case “Typical Case” is a typical example of the normal class period. Total number of evacuees was set as 960 people. There was not actual measurement of the refuge time, but the result of the simulation was from 920 seconds to 1,150 seconds. Judging from the result of "No classes", this simulation result would be near the observed value if measurement were performed.

In the third case "Maximal case", the approximately maximum number of people that could exist in this building was set. Total number of refugees was 1,810. About this case, at the time of the design of this building, it was estimated by a simple calculation that refuge would be completed in 1,200 seconds. However, the simulation result was from 1,684 seconds to 2,141 seconds. When they review an estimate of the refuge time from this building, these results will serve as a reference.

Table 1. Observed and Predicted Evacuation Time

No classes

	People
12F	130
11F	10
10F	10
9F	10
8F	70
7F	60
6F	10
5F	0
4F	0
3F	0
2F	110
EXIT	10
Total Exited	420
Observed Evacuees	396

Typical case

	People
12F	165
11F	70
10F	70
9F	50
8F	70
7F	50
6F	50
5F	85
4F	45
3F	135
2F	160
EXIT	10
Total Exited	960
Observed Evacuees	-

Maximal case

	People
12F	300
11F	100
10F	100
9F	100
8F	100
7F	100
6F	200
5F	200
4F	100
3F	200
2F	300
EXIT	10
Total Exited	1810
Observed Evacuees	-

Evaluation of Overall Evacuation Time

Evacuation Time (sec)	
Observed	510
Predicted	426 ～547

Evacuation Time (sec)	
Observed	-
Predicted	920 ～1150

Evacuation Time (sec)	
Designed*	1200
Predicted	1684 ～2141

*expected value at the construction of the building

5 Conclusion

In this study, multi agent-based refuge modeling and the simulator based on it were developed. These were applied to the evacuation of a high-rise building of a real university where there were a large number of students. The simulator estimated the time required for all people to evacuate and the time required for emergency services to arrive at the target floor. In addition, other useful data such as the influence when stairs and floors were blockaded by some collapse was also provided.

About the refuge completion time, the comparison between actual observed value and the simulation results was examined. As a result, when there were relatively few refugees, it is confirmed that simulation fits well the real measurement. In the case of a large number of refugees, it was understood that real evacuation time would be longer than the value calculated by a more simple method at the time of a building design.

If these analyzed simulation results are told to general persons beforehand, dangerous panic at evacuation can be avoided. Furthermore, it can be utilized for the design of stairs and the exit in new buildings that will be constructed in future.

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