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The Influence of Mental Factors on Fire Evacuation Behavior and the Effect of Introducing RFID and Cellular Phone

Masatora Daito[†] and Noriyuki Tanida[††]

Abstract. Evacuation from fire in an underground shopping mall poses both construction and mental problems regarding fire evacuation. In this paper, we implement mental factors into our models of human-smoke and human-human interaction during an evacuation as three parameters: walking speed, distance of vision and imitation behavior in our agent-based model. We also implement environmental variation as the speed and density of smoke into our model. We will reveal how a change in environment can affect evacuation time and how this behavior is influenced by certain mental factors. The result of the simulation shows that in the case of using active RFID (Radio Frequency Identification) tags and cellular phones, the end time of evacuation was more than 5.4 times quicker than that of ordinary evacuation.

Keywords: human communication, human-smoke interaction, imitation behavior, fire evacuation, agent-based simulation, active RFID tag and cellular phone

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1 Introduction

If emergencies such as fire accidents happen, people have to leave their environments quickly. Under such emergency circumstance, being inside of a mall poses high risks for survival. The site of an underground shopping mall has something in common with other sites [1]. In both instances, pedestrians tend to lose their precise location and overlook some exits [2-4]. Pedestrians sometimes tend to pass through the narrow exit without stopping during an evacuation. On the other hand, many pedestrians will concentrate at the wide exits. If many people are forced to evacuate through a limited number of wide exits, the evacuation time will be longer [4-5]. There are two ways to approach the solution to these problems; namely, from an architectonic side or from a human behavioral side. We reveal the behavioral side using an agent-based simulation. The behavioral side of research using agent-based models has been conducted by studying the role of a leader [6] and crowd behavior [7]. However, how a change in environment can affect evacuation time and how this behavior is influenced by certain mental factors has yet to be studied. Therefore, we analyze the results of these interactions. In addition, our previous research model was created on the premise that all pedestrians showed the same evacuation behavior patterns from the beginning of the simulation [8]. This premise has been revised in this work according to environmental variations and mental factors. The reason for this is the result of the fire evacuation questionnaire showing that the percentage of people who could quickly decide on an evacuation plan after hearing the fire alarm ring was only 26.3 percent [9]. In other words, people took their time in making an exit decision.

In this paper we first investigate the evacuation behavior of people in a smoke-filled environment using a model of interaction between a pedestrian and smoke (Human-Smoke Model). Secondly, through the interaction of humans with humans (the Human Communication Model), we investigate the evacuation behavior of pedestrians, who, after finding smoke communicates his or her evacuation plan without giving the direction of an exit to other pedestrian. However, if a pedestrian find a narrow exit, he/she tells direction of the exit to others who is also in the visible range of the exit. In both these two models, the pedestrian performs individual evacuation behavior. However, there is indirect interaction by way of the position of the pedestrians in response to others. In other words, people show a tendency towards mass behavior, that is, to do what other people do [4]. Thirdly, we investigate the influence of evacuation behavior by using a model of the imitation of other people's behavior (Imitation Behavior Model). The aim of this study is to reveal evacuation time and the influence of smoke using these three models. Each model has three cases, each containing four types of pedestrians: very sensitive, sensitive, normal, and insensitive to smoke. As a case study we use the Tenjin underground shopping mall in Fukuoka Prefecture in Japan.

2 Model of Agent-Based Simulation

2.1 Type of Agents

In this model, we use a pedestrian agent, an exit agent, a landmark agent, and a smoke agent. Each agent's role and rule of behavior is as follows:
1) The exit agent represents the exit sign.
2) The landmark agent represents the landmark of directions to the wide exit.
3) The smoke agent represents smoke.
4) The pedestrian agent represents the pedestrian. The attributes of the pedestrian consist of age, sex, and sensitivity to smoke. The pedestrians act according to behavioral rules. These behavioral rules are shown in Fig.1. At the initial step of simulation, the positions of the pedestrian agents are at random on the path, and they pick a random direction. If there is a wall in their direction of travel, they change direction. If these agents sense a smoke agent within 20 cells (15 meters), they look

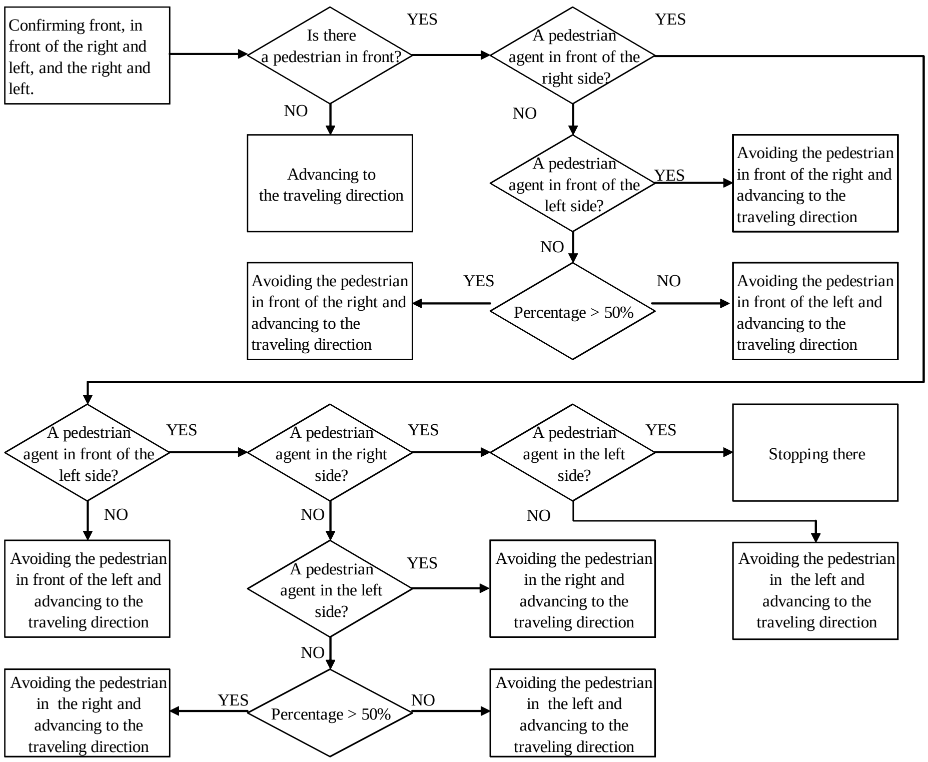

Fig. 1. Action rules for a pedestrian agent

for a landmark agent or an exit agent within 10 cells (7.5 meters). We follow a research for the measurement of the diffusion of smoke [10].

We use "Cs" to represent smoke density. The smoke density is represented by the smoke agent. According to a result of an experiment [11], allowable smoke density for people who are unfamiliar with the safety escape route is about 0.15/m in terms of an extinction coefficient. On the other hand, allowable smoke density for people who are familiar with the safety escape route is about 0.5/m. When Cs is less than 0.1/m, Cs has the consistency of 0.7m/sec. When Cs reaches 0.1/m, Cs will add a density of 0.00333/sec. The density variation of Cs is based on the data of an experiment in the Tokyo Kaijo Kasai Building in 1967. The distance of vision "G" is computed by 2.7/Cs [12]. The walking speed of the pedestrian is computed as shown below [13]:

$$v_{\mathrm{s}} = 0.128 \cdot C_{\mathrm{s}} \cdot v_{\mathrm{o}} \cdot \{\log_e (VA) - 0.567\} + v_{\mathrm{o}}, \tag{1}$$

where, v_{s} is the walking speed in smoke, v_{o} is the ordinary walking speed, and VA is the visual acuity. The value of VA is assigned the average of the visual acuity of research subjects in twenties. We set upper limits for 2.25 of Cs. This means that the pedestrian agents do not stop walking because of the smoke effect. The walking speed of the pedestrian under no lighting is 0.2-0.3 m/sec [14].

If the pedestrian agents recognize an exit agent, they turn to the exit and act according to the rule. The walking speed is also reduced by 45 percent at the stairway of exits. In the model of the interaction between humans and humans, if one pedestrian agent senses the smoke, he/she communicates with other pedestrian agent who is within their distance of vision "G", and appeals to the agent for evacuation. In addition, if one pedestrian agent finds a narrow exit, he/she also communicates with the other pedestrian agent, and transmits the exit direction. In the model of the imitation of other people's behavior, if one pedestrian agent senses the smoke, he/she will imitate the other pedestrian agent who is within his/her distance of vision "G".

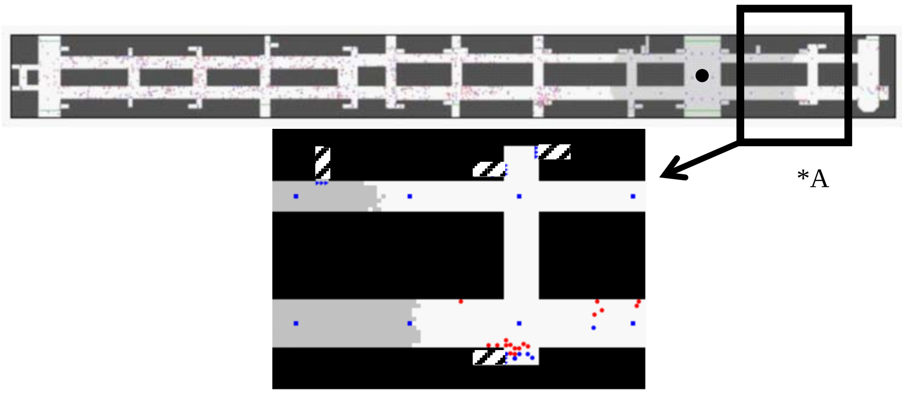

Fig. 2. Map of underground shopping mall

2-2 Layout of Agent-Based Simulation

A map of the Tenjin underground shopping mall is shown in Fig. 2. One cell of the model is a square 75 centimeters on each side. The outside frame of the black area represents the walls or shops, and the inside of the white area shows a path. The path consists of 19,921 cells. The hatched area represents an exit stairway (enlargement of *A in Fig. 2). The gray area shows a trail of smoke. The narrow exits are defined as having a width under three cells. The wide exits are defined as having a width over three cells. The triangles of Fig. 2 represent the location of exit agents. The square represents the location of landmark agents. The Tenjin subway station on the north side is defined as the starting point of the fire (see Fig. 2 black dot marks).

2-3 Personality of the Pedestrian Agent

The pedestrian agents have age group as a parameter, which is categorized into the ages of 15-19, 20-29, 30-39, 40-49, 50-59, and over 60. The pedestrian agent also has a sex (Male, Female) as a parameter. A normal walking speed of an agent is dependent upon the age group and sex (shown in Table 1). The pedestrian agent has a sensitivity to smoke as a parameter, which is categorized into 'very smoke-sensitive', 'smoke-sensitive', 'normal smoke-sensitive', and 'smoke-insensitive'.

Table 1. Normal walking speed of pedestrian agent

	Normal walking speed Ratio (%)	
Age groups	Male	Female
15-19	0.999	0.903
20-29	0.947	0.854
30-39	0.935	0.844
40-49	0.898	0.810
50-59	0.854	0.771
Over 60	0.836	0.754

Table 2. Population composition in the Tenjin underground shopping mall

		Male-Female Ratio (%)	
Age groups	Ratio of age (%)	Male	Female
15-19	17	6.12	10.88
20-29	33	11.88	21.12
30-39	11	3.96	7.04
40-49	9	3.24	5.76
50-59	17	6.12	10.88
Over 60	13	4.68	8.32

The ‘very smoke-sensitive’ is defined by pedestrian agents who can detect smoke by 100 percent. The ‘smoke-sensitive’ is defined by pedestrian agents who can sense smoke by 75 percent. The ‘normal smoke-sensitive’ is defined by pedestrian agents who can sense smoke by 50 percent. The ‘smoke-insensitive’ is defined by pedestrian agents who can sense smoke by 25 percent. 1,500 pedestrian agents are set on the simulation field. We add the questionnaire survey on the Tenjin underground shopping mall [15] to our model. The population rate by age and sex is shown in Table2. First, we use the three Cases to show human-smoke interaction. The fundamental walking speed of males and female is shown by empirical data [16-18]. The pedestrian senses the wide exit by 80 percent per step and the narrow exit by 20 percent per step within their field of vision. This probability is reflected in previous empirical data in evacuation research [19]. Next, we add three models to the Cases to see the effect of human communication and the imitation of other people’s behavior.

2-4 Settings and Outputs of Agent- Based Simulation

We use the models of the Human-Smoke Model (Case-1), the Human Communication Model (Case-2), and the Imitation Behavior Model (Case-3) (shown in Table 3). We categorize Case1 into three types. Case1-1 consists of four mental types of pedestrian agents, one of whom is very smoke-sensitive. This very smoke-sensitive of pedestrian agent is represented by a 40-percent rate at the initial step of simulation. In the same way, smoke-sensitive is represented by a 30-percent, normal smoke-sensitive are represented by a 20-percent, smoke-insensitive are represented by a 10-percent rate at the initial step of simulation. Case1-2 consists of very smoke-sensitive pedestrian agents at a 25-percent, smoke-sensitive at a 25-percent, normal smoke-sensitive at a 25-percent, and smoke-insensitive at a 25-percent at the initial step of simulation. Case1-3 consists of very smoke-sensitive at a 10-percent, smoke-sensitive at a 20-percent, normal smoke-sensitive at a 30-percent, and smoke-insensitive at a 40-percent at the initial step of simulation. We add the parameters of Human Communication to each Case and thus creating new cases: Case2-1, Case2-2, and Case2-3. In addition, the model regarding the pedestrian agents imitating other pedestrian agent behaviors is created in Case3-1, Case3-2, and Case3-3.

When Cs was 0.1/m, pedestrian agents walked in smoke, and 25 percent was added to the rate of the pedestrian agents’ perception. For instance, 25 percent is added to the rate of the pedestrian agents’ normal smoke-insensitive; therefore, that rate is changed to 50 percent. When Cs was 0.5/m, pedestrian agents walked in smoke, and 25 percent was added to the rate of pedestrians’ perception. For instance, 25 percent was added to the rate of pedestrian agents’ normal smoke-insensitive; therefore, that rate changed to 75 percent. That is, if Cs becomes high, many pedestrian agents begin to evacuate.

Table 3. Cases of simulation

		Very Sensitive	Sensitive	Normal	Insensitive
Case-1	Case1-1	40%	30%	20%	10%
	Case1-2	25%	25%	25%	25%
	Case1-3	10%	20%	30%	40%
Case-2	Case2-1	40%	30%	20%	10%
	Case2-2	25%	25%	25%	25%
	Case2-3	10%	20%	30%	40%
Case-3	Case3-1	40%	30%	20%	10%
	Case3-2	25%	25%	25%	25%
	Case3-3	10%	20%	30%	40%

When the all pedestrian agents are evacuated from the underground shopping mall, the simulation ends. There are five kinds of data used for the analysis as follows:

1) The end time of evacuation of each pedestrian agent; the pedestrian agent is separated by age group and sex.
2) Subtotal of evacuated pedestrian agents at the initial phase (in 400 steps) of evacuation
3) Simulation end time of evacuation completion of all pedestrian agents
4) Subtotal of pedestrian agents who evacuated at the initial phase of evacuation when Cs was 0.1/m and 0.5/m.
5) Total of pedestrian agents who evacuated when Cs was 0.1/m and 0.5/m.

We carry out the nine cases every fifteen times.

For comparison with the end time of evacuation by age group and sex, we add up the end time of evacuation by the attribute of pedestrian agent. To confirm the number of pedestrian agents who went out the underground shopping mall in 400 steps which means five minutes, we count the evacuated pedestrian agents from the underground shopping mall.

3. Results and Discussion

In this section, we discuss the results of nine Cases of our simulation. We discuss the Human-Smoke Model (Case-1), the Human Communication Model (Case-2), and the Imitation Behavior Model (Case-3). When compared with these three models, the Human Communication Model had the best results. The second best was the Human-Smoke Model, and the third, the Imitation Behavior Model (shown in Fig. 3). Evacuated pedestrian agents who walked in smoke are shown in Fig.4. The Human-Smoke Model was the most affected when Cs was 0.1/m. However, the Human-Smoke Model was the least affected when Cs was 0.5/m. The Imitation Behavior Model was the most affected when Cs was 0.5/m.

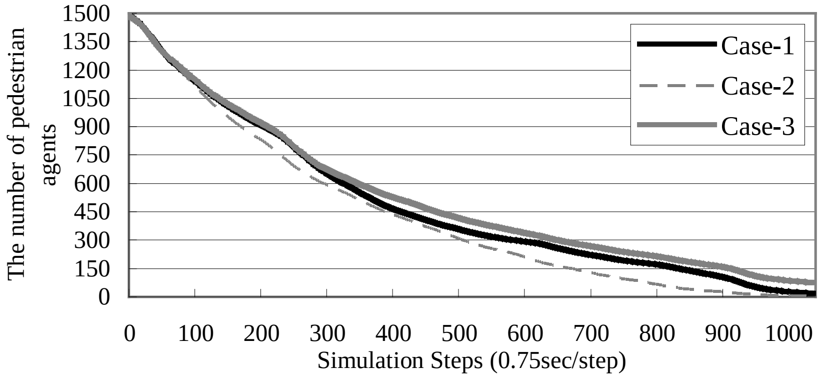

Fig. 3. Evacuation time in Case-1, Case-2 and Case-3

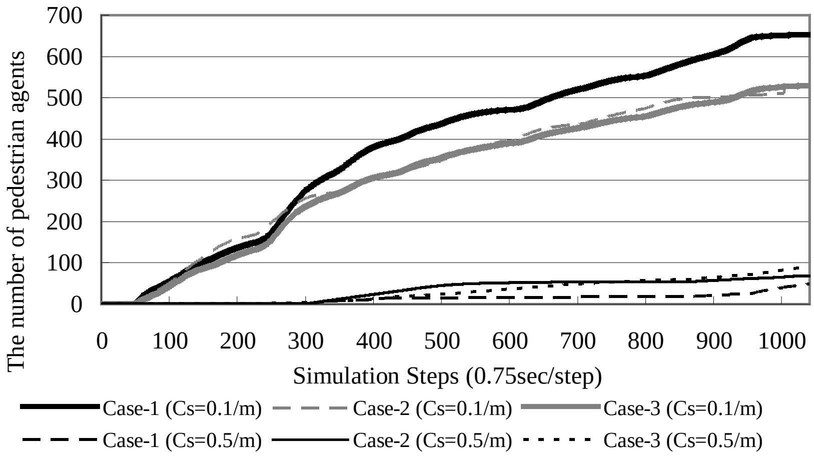

Fig. 4. Pedestrian agents who walked in smoke when Cs was 0.1/m and 0.5/m, respectively

Next, we discuss each model containing the pedestrians who are very smoke-sensitive, smoke-sensitive, normal smoke-sensitive, and smoke-insensitive. We compare the initial phase at 400 steps, which represents five minutes at the end of the simulation steps. Moreover, we compare the number of pedestrian agents who walked in the smoke and the final evacuation time.

In the initial phase in the Human-Smoke Model, the number of pedestrians who left the underground increased (age group 40-49, 50-59 and Over 60, male, female), but the number of very smoke-sensitive of pedestrian agents decreased (Shown in Table 4). However, the evacuation time increased (age group 40-49, 50-59 and Over60, male, female) with a decrease in the very smoke-sensitive of pedestrian agents at the end time of the simulation (Shown in Table 5). Although we expected that all of the very smoke-sensitive pedestrian agents evacuated in the initial phase would increase, the result of older agents such as those in the age groups of 40-49, 50-

Table 4. Initial phase (The percentage of evacuated pedestrian agents at 400 steps) (Case 1-1, Case 1-2 and Case 1-3)

	Age groups						Sex		
	15-19	20-29	30-39	40-49	50-59	Over 60	Male	Female	Total
Case 1-1	71.22	69.55	68.66	67.98	66.98	67.24	69.14	68.07	68.61
Case 1-2	69.34	70.08	70.21	68.62	68.50	68.29	69.85	68.49	69.17
Case 1-3	69.77	69.24	70.01	69.82	68.60	69.02	70.16	68.67	69.41

(Percentage by each age group and sex)

Table 5. End steps of simulation (Case 1-1, Case 1-2 and Case 1-3)

		Age groups						Sex		
		15-19	20-29	30-39	40-49	50-59	Over 60	Male	Female	Total
Case 1-1	Ave.End time	1108.57	1211.27	1272.10	1164.43	1071.90	1074.90	1100.49	1233.67	1167.08
	SD	215.41	429.08	97.35	76.32	279.78	341.87	160.56	319.37	239.97
	Maximum	1806.00	2595.50	1333.00	1193.00	1782.50	2345.00	1588.67	2096.33	1842.50
	Minimum	945.00	1015.50	953.00	938.00	1017.50	963.00	951.17	992.83	972.00
Case 1-2	Ave.End time	1082.43	1118.70	1226.17	1189.57	1092.63	1077.43	1104.99	1255.66	1180.32
	SD	82.14	274.25	73.49	64.57	413.83	403.60	164.02	273.27	218.65
	Maximum	1257.50	1866.00	1221.50	1190.00	2442.00	2292.00	1586.17	1836.83	1711.50
	Minimum	961.50	1035.50	994.50	963.00	1071.50	1002.50	965.33	1044.17	1004.75
Case 1-3	Ave.End time	1167.83	1233.33	1271.67	1225.70	1150.73	1128.20	1119.84	1323.69	1221.77
	SD	264.28	322.60	225.93	262.93	500.80	403.79	225.64	434.47	330.06
	Maximum	1927.50	2184.50	1868.00	1750.50	2822.50	2472.50	1781.83	2560.00	2170.92
	Minimum	943.00	1010.50	930.50	908.50	978.50	998.00	933.33	989.67	961.50

Table 6. The average number of pedestrains who walked in smoke when Cs reached 0.5/m (Case 1-1, Case 1-2 and Case 1-3)

		Age groups						Sex		
		15-19	20-29	30-39	40-49	50-59	Over 60	Male	Female	Total
Case 1-1	Ave. Walking in smoke	6.53	16.80	6.53	6.73	12.27	10.47	17.27	42.07	59.33
	SD	2.01	2.85	2.42	1.92	2.34	2.72	1.64	3.12	2.38
	Maximum	8.00	13.50	8.50	7.00	10.00	11.00	6.00	13.33	9.67
	Minimum	0.50	3.50	0.00	0.50	3.00	0.50	0.17	2.50	1.33
Case 1-2	Ave. Walking in smoke	8.60	17.53	6.47	5.53	12.73	11.53	17.33	45.07	62.40
	SD	1.33	3.63	1.71	1.62	2.26	2.95	1.83	2.67	2.25
	Maximum	7.00	16.00	6.00	6.50	11.00	11.50	7.33	12.00	9.67
	Minimum	2.00	4.00	0.00	0.50	3.50	1.00	0.50	3.17	1.83
Case 1-3	Ave. Walking in smoke	8.87	19.33	7.07	6.13	14.87	11.27	20.73	46.80	67.53
	SD	2.53	3.13	2.60	1.96	2.64	2.64	2.07	3.09	2.58
	Maximum	9.00	14.50	9.00	6.00	11.50	11.00	7.50	12.83	10.17
	Minimum	0.50	3.50	0.50	0.00	2.50	1.50	0.33	2.50	1.42

59 and over 60 was contrary to our expectations. Only the younger agents, under 40, could walk quickly to the exits. In the early phase, some of older agents waited to evacuate. Finally, Table 5 shows that as the ratios of the very smoke-sensitive increased, the end time of older pedestrian agents became short. However, a relatively high maximum value of each case of pedestrian agents over 60 shows that they have been in danger until the end. When Cs was more than 0.5/m, the distance of vision was less than 5.4 meters. Therefore, pedestrian agents (age group of 15-19, 20-29 and 50-59 and male and female) spent extra time looking for an exit, which prolonged traveling distance (Shown in Table 6).

According to the end time of the simulation on the Human Communication Model, when the number of very smoke-sensitive of pedestrian agents decreased, the evacuation time in Case2-3 was quicker than that of Case2-1 and Case2-2. The number of pedestrian agents, who walked in smoke when Cs was 0.1/m at the initial phase, was also reduced (age groups of 20-29 and 50-59 and male and female) (Shown in Table 7). The number of pedestrian agents, who walked in smoke when Cs was 0.1/m at end of simulation, increased (in almost all age groups except for 50-59) (Shown in Table 8). Characteristics revealed by comparing the three cases in this model showed that in the case of less very smoke-sensitive of pedestrian agents in Case, the number of pedestrian agents who walked in smoke was increased.

According to the end time in the simulation of the Imitation Behavior Model, when the number of very smoke-sensitive of pedestrian agents decreased, the evacuation time in Case3-3 was quicker than that of Case3-1 and Case3-2. The ratio of evacuated pedestrians who walked in smoke when Cs was 0.1/m in the initial phase is shown in Table 9. Age groups of 15-19, 20-29 and 50-59, and females in Table 9 show that the ratio of pedestrians passing through smoke became high as the rate of very smoke-

Table 7. The percentage of evacuated pedestrians passing through smoke when Cs reached 0.1/m in 400 steps (Case 2-1, Case 2-2 and Case 2-3)

	Age groups						Sex		
	15-19	20-29	30-39	40-49	50-59	Over 60	Male	Female	Total
Case 2-1	61.69	61.21	62.99	63.16	63.01	57.98	62.59	60.76	61.67
Case 2-2	63.47	60.84	58.82	63.75	59.36	56.03	60.59	60.17	60.38
Case 2-3	58.18	60.72	60.22	62.01	58.89	56.97	59.83	59.16	59.50

(Percentage by each age group and sex)

Table 8. The number of pedestrian agents walking in smoke when Cs reached 0.1/m (Case 2-1, Case 2-2 and Case 2-3)

		Age groups						Sex		
		15-19	20-29	30-39	40-49	50-59	Over 60	Male	Female	Total
Case 2-1	Ave. Walking in smoke	71.40	156.87	53.67	43.20	95.07	71.67	166.93	324.93	491.87
	SD	5.49	9.97	5.02	4.13	6.99	5.45	5.28	7.06	6.17
	Maximum	47.00	97.00	35.00	31.50	60.50	47.50	38.50	67.67	53.08
	Minimum	27.00	60.50	19.50	15.50	36.00	27.50	20.00	42.00	31.00
Case 2-2	Ave. Walking in smoke	76.13	160.47	57.93	46.93	87.53	74.73	165.60	338.13	503.73
	SD	7.16	7.54	6.34	5.10	6.37	5.06	4.53	7.99	6.26
	Maximum	51.00	94.00	38.50	31.50	52.50	45.00	35.83	68.33	52.08
	Minimum	26.50	67.00	19.00	13.50	28.50	28.00	21.00	39.83	30.42
Case 2-3	Ave. Walking in smoke	79.87	169.47	59.73	47.20	93.20	79.27	177.27	351.47	528.73
	SD	6.33	7.83	5.00	4.70	4.37	6.79	5.17	6.50	5.83
	Maximum	50.50	104.00	38.00	32.50	54.00	51.00	39.00	71.00	55.00
	Minimum	27.50	74.50	20.00	15.00	40.00	29.00	20.50	48.17	34.33

Table 9. The percentage of evacuated pedestrians passing through smoke when Cs reached 0.1/m at 400 steps (Case 3-1, Case 3-2 and Case 3-3)

	Age groups						Sex		
	15-19	20-29	30-39	40-49	50-59	Over 60	Male	Female	Total
Case 3-1	54.00	57.91	57.42	60.13	55.09	58.82	57.94	56.52	57.23
Case 3-2	57.62	58.01	56.13	56.19	56.74	60.40	57.34	57.69	57.52
Case 3-3	58.82	58.77	59.70	57.87	57.26	56.45	58.28	58.01	58.15

(Percentage by each age group and sex)

Table 10. The number of pedestrian agents walking in smoke when Cs reached 0.1/m (Case 3-1, Case 3-2 and Case 3-3)

		Age groups						Sex		
		15-19	20-29	30-39	40-49	50-59	Over 60	Male	Female	Total
Case 3-1	Ave. Walking in smoke	82.20	175.70	60.90	45.70	93.80	67.00	177.20	348.10	525.30
	SD	5.17	8.53	5.99	5.49	6.41	4.77	4.51	7.60	6.06
	Maximum	49.00	104.00	40.00	32.50	58.50	39.50	37.83	70.00	53.92
	Minimum	33.00	77.00	22.50	15.00	35.50	23.00	23.33	45.33	34.33
Case 3-2	Ave. Walking in smoke	80.36	175.55	56.55	49.55	97.45	71.73	184.91	346.27	531.18
	SD	7.64	7.95	4.52	5.08	5.66	6.10	5.01	7.31	6.16
	Maximum	56.50	100.50	34.00	32.50	57.00	44.00	38.67	69.50	54.08
	Minimum	29.00	75.50	21.50	15.50	38.50	26.00	22.83	45.83	34.33
Case 3-3	Ave. Walking in smoke	85.80	175.47	58.87	50.60	90.13	74.60	193.93	341.53	535.47
	SD	6.10	8.67	5.73	5.37	6.04	3.68	5.35	6.52	5.93
	Maximum	53.50	103.00	41.50	36.50	53.00	43.00	42.17	68.00	55.08
	Minimum	32.00	73.00	20.50	17.00	35.00	31.00	22.50	47.00	34.75

Table 11. End steps of simulation (Case 3-1, Case 3-2 and Case 3-3)

		Age groups						Sex		
		15-19	20-29	30-39	40-49	50-59	Over 60	Male	Female	Total
Case 3-1	Ave.End time	2129.55	2382.85	2801.35	2619.80	2286.45	2353.90	2153.00	2781.98	2467.49
	SD	554.57	715.19	564.75	671.55	590.78	756.22	638.26	646.10	642.18
	Maximum	3235.00	4037.00	3413.50	3379.50	3780.50	3785.50	3336.33	3874.00	3605.17
	Minimum	1348.50	1667.00	1514.50	1250.50	1911.00	1586.50	1233.17	1859.50	1546.33
Case 3-2	Ave.End time	2026.82	2421.91	2674.50	2370.50	1949.23	1930.50	2030.09	2629.38	2329.73
	SD	764.72	786.77	702.01	755.98	604.03	666.77	682.14	744.62	713.38
	Maximum	3576.00	3634.00	3472.00	3444.50	3586.50	3842.00	3421.67	3763.33	3592.50
	Minimum	1177.00	1223.50	1020.50	1144.50	1729.00	1541.50	1153.67	1458.33	1306.00
Case 3-3	Ave.End time	2011.57	2183.07	2438.00	2167.53	1830.60	1838.97	1913.37	2434.22	2173.79
	SD	644.37	701.29	566.58	773.13	665.47	597.93	584.64	731.61	658.13
	Maximum	3313.00	3579.50	3116.50	3843.00	3539.00	3555.50	3149.50	3832.67	3491.08
	Minimum	1225.00	1269.50	1129.00	1145.00	1342.00	1353.00	1142.33	1345.50	1243.92

sensitive of pedestrian agents came down. The number of pedestrian agents who walked in smoke when Cs was 0.1/m at end of simulation is shown in Table 10. As the rate of very smoke-sensitive of pedestrian agents came down, the age group of 40-49 and over 60 in Table 10 increased. Characteristic revealed by comparing the three cases in this model showed that in the case of less very smoke-sensitive of pedestrian agents, the pedestrian agents who walked in smoke was reduced (almost all age groups except for 20-29 in Table 11). That is, the traveling distance became long, since very sensitive pedestrian agents imitate others in early stage in Case 3-1.

Therefore evacuation time of Case 3-1 also became later than evacuation time in Case 3-2 and Case 3-3.

Evacuation time of every Case-3 was later than that of other cases. The imitation of other people's behavior represented pedestrians was not guided to the beneficial directions. This means many pedestrian chose misleading directions. Therefore, some leaders or tools for directing to optimum exit are required to achievement of early evacuation. Additionally, we implement the tool [8] using active RFID (Radio Frequency Identification) tags and cellular phones into our model. We use the models of the Human-Smoke Model using active RFID tags and cellular phones (Case-4), the Human Communication Model using active RFID tags and cellular phones (Case-5), and the Imitation Behavior Model using active RFID tags and cellular phones (Case-6) (shown in Table 12). These cases consist of very smoke- sensitive pedestrian agents at a 25-percent, smoke-sensitive at a 25-percent, normal smoke-sensitive at a 25-percent, and smoke-insensitive at a 25-percent at the initial step of simulation. We also add an idea to Case-6. The idea which "Please tell the people around you "Please follow me!"" is displayed on pedestrians' cellular phone. We carry out the six cases every fifteen times.

Table 12. Cases of simulation using RFID and cellular phone

		Diffusion rate of active RFID tags and cellular phones	Very Sensitive	Sensitive	Normal	Insensitive
Case-4	Case4-1	50%	25%	25%	25%	25%
	Case4-2	100%	25%	25%	25%	25%
Case-5	Case5-1	50%	25%	25%	25%	25%
	Case5-2	100%	25%	25%	25%	25%
Case-6	Case6-1	50%	25%	25%	25%	25%
	Case6-2	100%	25%	25%	25%	25%

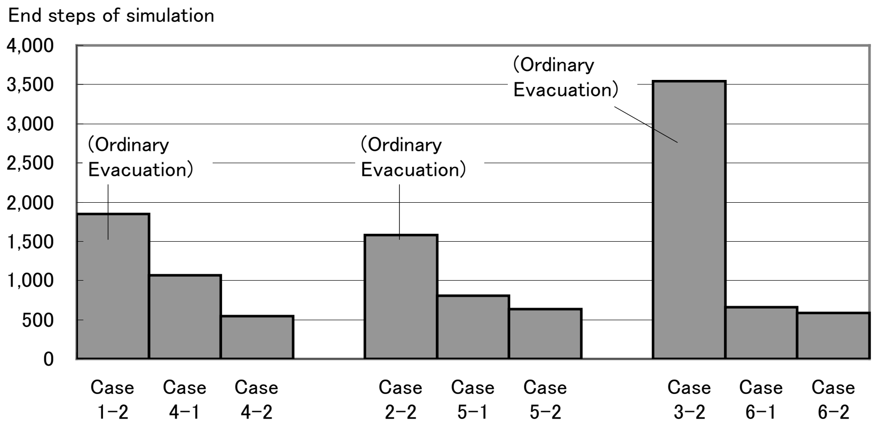

Fig. 5. End steps of simulation (comparison of normal evacuations with evacuations using cellular phone)

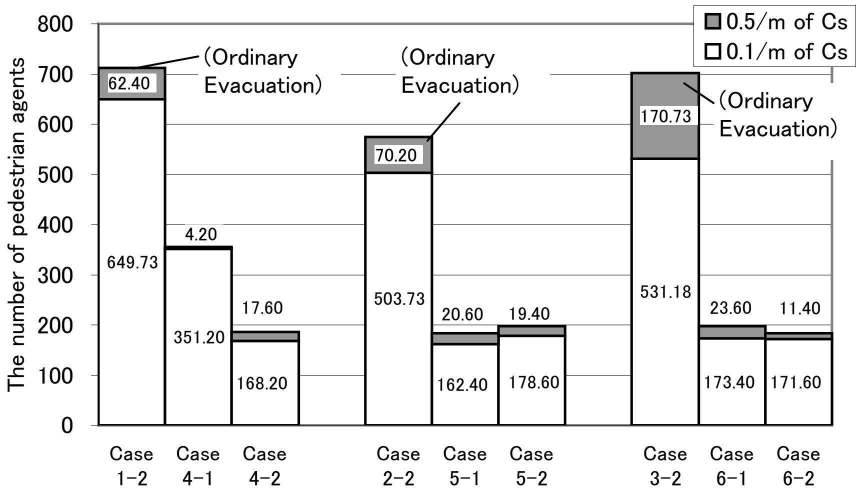

Fig. 6. Pedestrian agents who walked in smoke when Cs was 0.1/m and 0.5/m

The results of the simulation, the end time of Case4-1 was 1.7 times quicker than that of Case1-2 (Ordinary Evacuation) (Shown in Fig. 5). The end time of Case4-2 was also 3.4 times quicker than that of Case1-2. It is noteworthy that the end time of Case6-1 was 5.4 times quicker than that of Case3-2 (Ordinary Evacuation).The number of pedestrian agents who walked in smoke was also reduced by using RFID tag and cellular phone (Shown in Fig. 6).

4. Conclusion

In this research, we implemented mental elements as four parameters: smoke, distance of vision, walking speed and imitation behavior in our model. We also implemented environmental variation as speed and density of smoke. The following results were obtained from the relation of such mental elements and environmental variation.

According to the Human-Smoke Model, in case of individual evacuation behavior, the ratios of very smoke-sensitive of pedestrian agents became high; in other words, the more pedestrian agents were able to avoid smoke and evacuate quickly. According to the Human Communication Model, in the case of individual evacuation behavior, the ratios of very smoke-sensitive of pedestrian agents became high, and more pedestrian agents were able to avoid smoke. In addition, if we take this case, Case-2, as total evacuation time, Case-2 is quicker than Case-1 (the second best) and Case-3 (the third best). According to the Imitation Behavior Model, in the case of crowd behavior during evacuation, the ratios of very smoke-sensitive of pedestrian agents became high, and more pedestrian agents went into smoke and evacuate slowly. That is, the traveling distance became long, since very smoke-sensitive of pedestrian agents imitate others in the initial phase, but went into the smoke in a later phase when Cs was 0.5. These results indicate that the pedestrian agents who imitated others were not well guided in the optimal direction of the evacuation. Therefore, we implemented the tool [8] using active RFID tags and using cellular phones into our model. We also added an idea to Case-6. The idea which "Please tell the people around you "Please follow me!"" was displayed on pedestrians' cellular phone. The results of the simulation, end time of Case6-1 was 5.4 times quicker than that of Case3-2 (Ordinary Evacuation).The number of pedestrian agents who walked in smoke was also reduced by using RFID tag and cellular phone.

In this research, evacuation behavior was considered mainly from the relationship of smoke to distance of vision and the walking speed of the pedestrian. When pedestrians actually make an evacuation, panic sometimes occurs and there are pedestrians who run to the exit, fall to the floor, and are injured.

For future research we intend to further discuss the elements in our model.

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