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Applying Active Dynamic Signage System in Complex Underground Construction

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Abstract— In the event of emergency evacuations in large-scale public buildings, the complexity and capacity of the building are factors that prolong the egress time for the public and hinder the management of the risks pertinent to the evacuation route. Therefore, improving the effectiveness of a signage system for emergency evacuation is crucial. A previous study which was designated by E.R. Galea, developed an Active Dynamic Signage System for directing people toward safety exits according to the surrounding environment. In this study, we used the Dr.Galea'sprevious experimental result of different signage systems as the basis for setting the parameters of an evacuation simulation software program. After verifying the consistency of the simulation and previous experimental results, we applied the same parameter configuration to a more complex setting and simulated the smoke spread situation by using Fire Dynamics Simulator. This study investigated the difference between conventional signage systemsand Active Dynamic Signage System. Given that the origin of the fire is at the same point, we also examined the effectiveness of these two systems in evacuating people through different emergency exists and their effect on the safety of the evacuees.

Index Terms— large-scale public buildings, egress time,evacuation route, Active Dynamic Signage System, conventional signage systems, evacuation simulation software,Fire Dynamics Simulator (FDS).

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1 INTRODUCTION

The present study was conducted using simulation software [1], [2]to analyze theeffectiveness of a conventional signage systems and an Active Dynamic Signage System (ADSS) in a specific setting. Existing experimental results[3]related to this study were employed as the basis for determining the effect of signage on people's selection of safety exits. After verifying the consistency between the simulation results[1], [2] and experimental results, we adopted the parameter configuration as a model and applied the model into a more complex setting. Meanwhile,Fire Dynamics Simulator (FDS) [1]was employed to generate smoke simulation information for investigating the simulation results of the two types of signage system as well as the effectiveness of strategies for choosing different emergency exists.

In this section, an overview of the current situation regarding emergency exit signs and Active Dynamic Signage System is provided, in addition to the predicament of existing signage system for events of fire disasters. Next, the technological development of evacuation simulation software is described, and the features of Pathfinder used in this study are introduced. Finally, simulation results are examined to determine the potential risk of casualties caused by fire disasters.

1.1 Signage Lighting and Signage System

Emergency exit signs or emergency lightsareaimed at indicating the location of the nearest exit in case of fire or other emergency for people who are unfamiliar with the place they are in. Nowadays emergency exit signs are prevalently used in large-scale buildings across the world. In various countries, the hardware specification and setup methods for such signs are subjected to legal regulations [4].

Although large public settings have extensively used emergency exit signs to guide evacuation routes, past studies have indicated that only 38% of people paid attention to conventional static emergency signageeven if the signs are positioned right in front of them when they are evacuating from an unfamiliar setting [3], [5], [6], [7]. Conventional signage systemscan only convey single and passive information, rather than altering the egress route in response to a fire disaster. This deficiency hinders the maximum effectiveness of conventional signage systemsin case of emergencies. Therefore, the development of ADSS is intended at solving problems associated with conventional signage systems, with expectation of responding to emergency situations and guiding evacuees to a safe exit route.

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Fig.1. Conventional signage systems (upper) and ADSS (lower)

1.2 Evacuation Simulation Software and Pathfinder

Fire dynamics simulator (FDS)is primarily based on computational fluid dynamics (CFD)[1], [8]. FDS such software of CFD model involves converting numerical values measured from a fire disaster zone into parameter configuration for computation to simulate fire growth, fire spread, smoke spread, and diffusion of flammable gas. Subsequently, necessary information (e.g., temperature of the site of fire, smoke concentration, and carbon monoxide value[9], [10], [11]) is acquired and integrated with simulation results to evaluate the potential risks fire disasters are likely to impose on the life and property of people. Thus, a comprehensive fire prevention safety performance design can be devised. FDS can be assumed as a virtual experiment conducted through a computer to accumulate multiple experimental data for comparative analysis of distinct evacuation scenarios [8], [12], [13], [14].

This study primarily used Pathfinder as the chief evacuation simulation tool [2]. Pathfinder simulator was produced by Thunderhead Engineering Consultants, Inc. It is an agent-based egress and human movement simulator which was provides a graphical user interface for simulation design and execution as well as 2D and 3D visualization tools for results analysis. FDS model [1]and its relevant information such as carbon dioxide volume fraction, carbon monoxide volume fraction, oxygen volume fraction, temperature, soot visibility and FED of each agent also can import to the Pathfinder simulation model.

The Pathfinder calculation of Fractional Effective Dose (FED)[2] uses the equations described in the SFPE Handbook of Fire Protection Engineering, 5th Edition. The implementation is the same as used in FDS+EVAC [FDS+EVAC, 2009], using only the concentrations of the narcotic gases CO, CO_2, and O_2 to calculate the FED value.

This calculation does not include the effect of hydrogen cyanide (HCN) and the effect of $CO_2$is only due to hyperventilation.

$$FED_{tot} = FED_{CO} \times V_{CO_2} + FED_{O_2} \qquad (1)$$

1.3 Life-Threatening Factors in a Fire Disaster

High temperature and burning situations in a fire setting, including thermal effects, hypoxia, and smoke toxicity, are the principal factors endangering human life in a fire disaster [15], [16], [17]. First, the high temperature of a burning fire generates thermal effects that result in an ambient temperature of 80°C-120°C (176°F-248°F). Core body temperatures above approximately 43°C (109°F) are generally fatal unless treated[15].

Second, oxygen constitutes 20.9% of the atmosphere [18]. However, burning fire consumes oxygen, resulting in hypoxia among individuals present at the fire-burning site. When oxygen level drops to 15%, it exerts a trace amount of influence on the human body. As oxygen level drops from 15% to 10%, disorientation and loss of judgment result, and when oxygen level drops below 10%, unconsciousness occurs, followed rapidly by cessation of breathing and death.

Finally, smoke toxicity of a fire-burning site is attributed to combustion products of a fire disaster, which when inhaled or exposed to skin, they exert distinct levels of toxic effect on the human body such as eye irritation or respiratory tract irritation, or systematic influences on physical functions. These products include CO, CO_2,halogen oxoacids (hydrogen fluoride, hydrogen chloride, and hydrogen bromide), suspended particles (e.g., ash, soot, etc.) [16][19]. General toxic potency assessments for combustion products are chiefly based on the response of test subjects (e.g., mice) in a specific time to combustion products. Responses may either be lethality or incapacitation. The concentration of combustion products presents a positive correlation with theextent of the response. Particularly, the toxic potency of combustion products is typically measured using fractional effective dose (FED)[1], [2], [16], [17]. According to National Fire Protection Association (NFPA) 921[20], the mixture of gaseous toxicants would incapacitate or be lethal to 50% of exposed individuals when FED value equals 1.0[16], [20]. The certain effects of FED on the percentage of evacuees is hard to define.Nevertheless, an FED value of 0.3 relates to vulnerable populations, whereas an FED value of 3.0 represents the threshold in which the majority of population would likely become incapacitated [21].

2 EXPERIMENTAL METHODS

A previous study conducted a full-scale evacuation trial at a train station in Barcelona, Spain by using conventional signage systems and ADSS to analyze whether participants use indicated exit or nearest exit and to examine the effectiveness of both signage systems by Dr. Galea[3]. In reference to, the present study conducted a two-stage software-based simulation. The first stage involved verifying the feasibility of the simulation software; specifically, the results of the aforementioned study were used as the basis for parameter deduction and simulation software was employed to reproduce real-life scenario. Subsequently, the consistency between simulation and experimental results was verified to confirm that the data were feasible for extension to other settings. The second stage entailed applying the experimental data of to a specific setting(underground parking lot) for ascertaining the effects of exit options[2], egress effect, and FED inhaled at the fire-burning site when conventional signage systems and ADSS were used.

2.1 Parameter Estimation and Simulation Settings

In this study, parameters for a fire incident simulation were configured according to the statistical data presented by [2]. Regarding Stage 1 of the simulation in the present study, we adopted the results of experiment TS2.1 involving use of conventional signage systems as shown in Table 1. For Evacuation Pattern TS2.1_P4, 118 out of 149 participants (79%) noticed the signs and used the nearest exit. This evacuation behavior was defined as “evacuees who used the nearest exit.” The remaining participants (31 person; 21%) did not notice the sign and were therefore defined as “followers,” who simply followed others when evacuating. In the conventional signage systems simulation setting, two types of behaviors were categories, namely “evacuees who used the nearest exit” (79%) and “followers” (21%).

TABLE 1
MODEL SETTINGS ADOPTED BY [3]

Evacuation pattern	Number of participants	Initial location	Nearest exit	Used Exit	Type of sigh(s) on chosen route	Number of participants noticed sign(s)
TS2.2 P1	59	Box 1-4	Exit A-C	Exit A-C	No entrance sign	45(76%)
TS2.2 P2	31	Box 1-4	Exit A-C	Exit D	No entrance sign and flashing arrow sign	28(90%)
TS2.2 P3	56	Box 5-7	Exit D	Exit D	Flashing arrow sign	50(89%)
TS2.2 P4	149	Box 1-7	Exit A-D	Exit A-D	Standard static sign	118(79%)

Three behavioral modes (TS2.2 P1 to TS2.2 P3), shown in Table 1, were categorized according to the location of the participants and their chosen exits determined in Experiment TS2.2 involving ADSS. Therefore, in Stage 2 of the ADSS simulation, the number of participants were configured according to the different locations of the train station (as shown in Table 1), and Exit D was set as the indicated exit. The simulation was aimed at determining the outcomes when participants at their initial location use the indicated exit (Exit D) and the nearest exit. In particular, Evacuation Patterns TS2.2_P1 and TS2.2_P2 show that the initial location of the participants was at Box 1-4 and the nearest exit was A-C, and these two patterns were distinguished depending on whether the participants took the nearest exit (Exit A-C) or the indicated exit (Exit D). As indicated Table 1, 59 participants demonstrated pattern TS2.2_P1, in which they did not use the indicated exit and still chose the nearest exit. Of these 59 participants, 45 of them noticed the sign, indicating that they “used the nearest exit” whereas 14 of them were “followers.” For Pattern TS2.2_P2, 31 participants used the indicated exit, of which 28 noticed the signs and followed them and these participants were regarded as “evacuees who used the indicated exit,” and 3 participants did not notice the signs (making them “followers). For Pattern TS2.2_P3 in which Exit D was designated as the nearest exit and the indicated exit; 50 out of 56 evacuees noticed the signs (“evacuees who used the indicated exit”) and 6 were “followers.”

Statistics of TS2.2_P1 and TS2.2_P2 indicate that of the 90 participants, 45 (50%) were “evacuees who used the nearest exit,” 28 (31%) were “evacuees who used the indicated exit,” and the rest of 17 (19%) were “followers.” However, although the initial location in Patterns TS2.2_P1 and TS2.2_P2 was Box 1-4, the chosen exits differed in both patterns. Therefore, the 19% followers were categorized according to the ratio of “evacuees who used the nearest exit” and “evacuees who used the indicated exit” (45:28). In doing so, 11.875% followed evacuees who used the nearest exit and 7.125% followed evacuees who used the indicated exit. Among the 56 participants who demonstrate Pattern TS2.2_P3, 50 of them (89%) were “evacuees who used the indicated exit” and 6 of them (11%) were followers. The aforementioned results are summarized in Table 2.

TABLE2
DEFINITION AND SETTING OF EACH EVACUEE
IN THE SIMULATION OF BARCELONA STATION

The setting of Trial 1 in a station of Barcelona:		
	Action	Percentage
All boxes	Evacuees who used the nearest exit	79%
	Follower(follow evacuees who used the nearest exit)	21%
The setting of Trial 2 in a station of Barcelona:		
	Action	Percentage
Box-near exit D	Evacuees who used the indicated exit	89%
	Follower(follow evacuees who used the indicated exit)	11%
Box-near exit A,C	Evacuees who used the nearest exit	50%
	Evacuees who used the indicated exit	31%
	Follower(follow evacuees who sued the nearest exit)	11.875%
	Followers(follow evacuees who used the indicated exit)	7.125%

Next, under the Behavior setting in Pathfinder [2], the ratios of evacuees choosing their respective emergency exit were set according to the aforementioned parameter configuration to verify the feasibility of using software simulation to reproduce real-life situations.

2.2 Feasibility Verification

To confirm the feasibility of software simulation, this study established a 3D model of Barcelona station according to the previous study by Dr.Galea. Subsequently, we allocated identical number of people in each area according to the original experimental scenario [3] and then used Pathfinder [2]to simulate the conventional signage systemsand ADSS for comparing the difference between the simulation result and previous experimental results.

Fig.2. 3D model of the Barcelona station by using Pathfinder

Through a software simulation, a comparison of TS2.2 Trial 2 results and original experimental data was obtained:

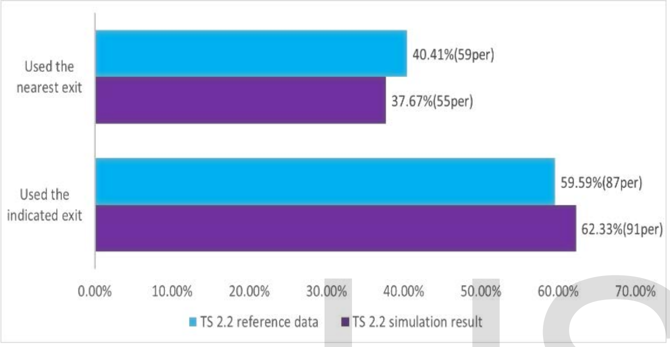

Fig.3. Comparison of Barcelona station experimental data (person as per)

The simulation results revealed that 91 evacuees used the indicated exit, accounting for approximately 62.33% of the total, and this value differed from the experimental result by not more than 4%. Repeated simulation attempts yielded an error of at most 4%. Therefore, we assert that these experimental settings can be used as the data model for application to other settings in order to simulate the use of conventional signage systems and ADSS in an event of emergency evacuation. Furthermore, when conventional signage systemsare used, all evacuees tend to use the nearest exit, rendering a nonsignificant difference between the simulation and experimental results.

3 EXPERIMENTAL SETUP

In the aforementioned section, reliable verification of the signage system simulation was achieved. In this section, Stage 2 of the software simulation was performed, in which the parameter configurations derived from an existing experiment [3]were applied to a simulation involving a more complex setting (underground parking lot). In addition, the experimental setup of this study was composed of two portions, Trial 1 (use of conventional signage systems setting) and Trial 2 (use of ADSS setting and an exit was designated). After obtaining the egress route of evacuees, we used FDS-derived smoke simulation information [1], [3], [22] to investigate the difference and effects of the two systems.

3.1 Research Setting and Planning

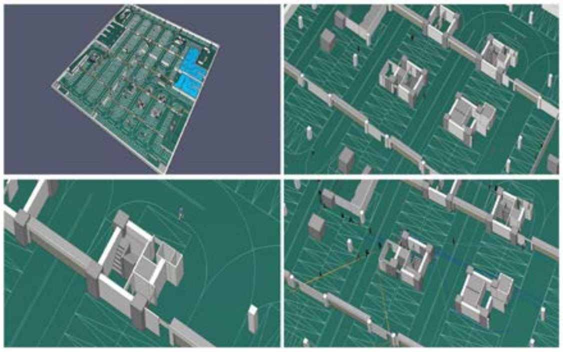

Fig.4. Pathfinder 3D model of a parking lot

For this study, we selected an underground parking lot (Level B5) as the simulation setting (for convenience, the following “underground parking lot” refers to “B5”). B5has a floor area of approximately 24,000 m2, of which 19,000 m2 constitutes the floor area of the evacuation route with a floor height of 3 m. There are 11 compartments for the evacuation route, with each measuring an average area of 1,800 m2. To facilitate discussion, we sequentially named the compartments as Compartment 1-11. The floor level has four exits that lead to the ground floor for evacuation. In particular, the nearest exit of an area is based on the Manhattan distance [2], [23]. Also, in according to the Egress complexity of a building, the movement of visitors in new surroundings represents an uncertain environment and only by moving around the area is new information absorbed until e.g. an exit is found[24]. Therefore, we can definition to each compartment of nearest exit. The nearest exit corresponding to each area is illustrated in Fig. 5 below.

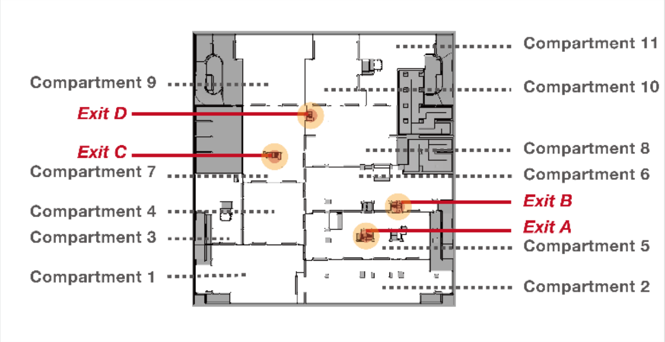

Fig.5. B5 compartments and exit floor plan

3.2 Parameter Configuration

Concerning simulation setting, 10 evacuees were placed in each compartment, and according to the inference made in Section 3.2, Trial 1 and Trial 2 exits were selected as shown in Table 3. Noticeably, Exit A in Trial 2 was regarded as the indicated exit. Therefore, in reference to the aforementioned parameter setting approach, Compartments 2 and 5 were configured to use the nearest exit as the indicated exit, whereas the other compartments were set to use the nearest exit.The setting of Trial 1 in B5:

TABLE3
DEFINITION AND SETTING OF EACH EVACUEE USED IN THE PARKING SIMULATION

The setting of Trial 1 in B5 of underground parking lot		
	Action	Percentage
All Compartments	Evacuees who used the nearest exit	79%
	Follower(follow evacuees who used the nearest exit)	21%
The setting of Trial 2 in B5 of underground parking lot		
	Action	Percentage
Compartments2, 5	Evacuees who used the indicated exit	89%
	Follower(follow evacuees who used the indicated exit)	11%
Compartments 1, 3-4, 6-11	Evacuees who used the nearest exit	50%
	Evacuees who used the indicated sign	31%
	Follower(follow evacuees who sued the nearest exit)	11.875%
	Followers(follow evacuees who used the indicated exit)	7.125%

To ascertain whether the original experimental data of Trial TS2.2 can serve as a data model for application in other specific setting, we compared the B5 simulation results, Barcelona station simulation results, and the original experimental data of Trial TS2.2. The simulation results indicated that in B5, 44 evacuees used the nearest exit (40%) and 66 evacuees used the indicated exit (60%). These results differed by not more than 3% to those of the station in Barcelona and not more than 1% to the original experimental data of Trial TS2.2. Following multiple simulation verifications, the differences were all smaller than the aforementioned proportion, indicating that the simulation results of B5 and station in Barcelona accord with the original experimental data of Trial TS2.2. Regarding conventional signage systems, because all evacuees used the nearest exit, comparison of difference was not performed. Based on the aforementioned discussion, the original experimental data were used as the data model, which yielded similar results under distinct simulation scenarios. Therefore, we extended the data to a specific setting for simulating a fire-burning site in B5.

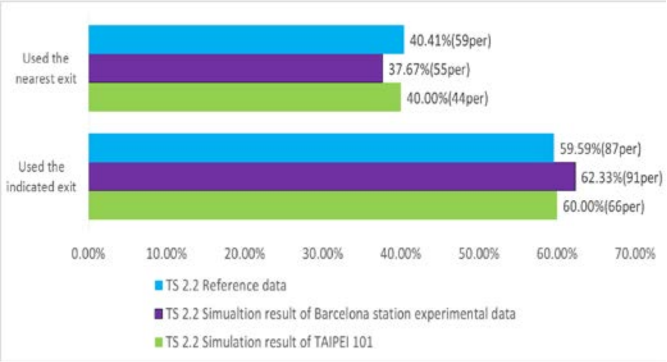

Fig.6. Comparison of reference data, Barcelona station experimental data, and B5 parking simulation results (person as per)

3.3 Fire Dynamics Simulator and Delay Time Setting

This study employed FDS to simulate fire in B5. The purpose was to determine how fire spread situations during evacuation attempts are related to the evacuation behavior of evacuees. The source of fire was set as polyurethane according to the NFPA Handbook[25]; subsequently, standard settings for large areas were configured according to the NFPA 92B [27]. Given that the source of fire is designated at Exit C, the FED inhaled by each evacuee was calculated for statistical analysis.

TABLE 4
REQUIRED SAFE ESCAPE TIME (RSET) SETTING

Accidents	Mean time
Fire and/or smoke detection	60s
Identification of fire location	20s
Alarm and announcement	30s
Egress route selection	10s
Egress in process	Depend on movement time of each scenario
RSET	120s+Egress in process

According to [26], Pathfinder considering delay time in advance reflects real-life situations. In addition, previous studies [28], [29], [30]have referred to the required safe egress time (RSET)[30], [31], [32], [33]for large areas, which is composed of action time plus detection time and reaction time. As table 4, the detection time and reaction time were approximately 120s (2 min), which is composed of the following times: the average time of fire and smoke being detected=60s; the time elapsed before location of fire ignition is confirmed=20s; the time when fire alarm and broadcast were activated=30s; evacuee response time to the alarm=10s. The action time was obtained according to different scenarios. Thus, evacuees only started evacuating 120 s after the fire was ignited. Therefore, the delay time in Pathfinder [2] was set as 120s.

4 EXPERIMENTAL RESULT

According to the experimental results of Trial 1 (conventional signage systems) and Trial 2 (ADSS), we examined the exit selections, overall egress time, and inhalation of toxic gas based on FED values.

4.1 Exit Selections and Egress Time

The selected exits are listed in Table 5. First, the simulation result of Trial 1 (conventional signage systems) indicates that Exits A-D were used by 21.82%, 9.09%, 32.73%, and 36.36% of evacuees, respectively. The simulation result of Trial 2 (ADSS) shows that Exit A (the indicated exit) was used by 60% of all evacuees, whereas Exits B-D were used by 4.5%, 17.3%, and 18.2% of the evacuees.

TABLE 5
USAGE OF EXITS IN TRIAL 1 AND TRIAL 2

Trial 1:Used exit	Exit A	Exit B	Exit C	Exit D
Percentage of used exit (%)	24per (21.82%)	10per (9.09%)	36per (32.73%)	40per (36.36%)
Trial 2:Used exit	*Exit A (indicated exit)*	Exit B	*Exit C (fire on this exit)*	Exit D
Percentage of used exit (%)	66per (60.00%)	5per (4.50%)	19per (17.3%)	20per (18.2%)

According to Trial 1 simulation result, the total egress time was 204s, whereas the total egress time was 250s in Trial 2, which is 46s longer than the time in Trial 1 as table 6. Examining Trial 1 (conventional signage systems) shows that evacuees typically used the nearest exit and therefore exhibited shorter egress time. The overall egress speed in Trial 1 was faster than that in Trial 2 (ADSS)[34]. Total egress time is delay time with spending time on evacuation.

TABLE 6
TOTAL EGRESS TIME ELAPSED

	Trial 1 - Standard Static sign	Trial 2 – ADSS (indicated –exit A)
Total egress time (S)	204.025	250.025

4.2 FEDAccumulative Value

Regarding FED cumulative value, Trial 1 and Trial 2 simulation results were compared to show a comparison of FED inhaled by evacuees, as illustrated in Fig. 7.

As indicated in Fig. 7, in Trial 1 simulation where conventional signage systems was used, 36 evacuees registered an FED value of ≥3.0 (32.73%) with an average FED of 34.21. By contrast, in Trial 2 where ADSS was used, 19 evacuees measured an FED value of ≥3.0 (17.27%) with an average FED of 17.83, which is almost half that in Trial 1. Combining the two simulation results shows that the accumulative FED obtained in Trial 2 was less than half of that obtained in Trial 1. This result indicates that evacuating from the indicated exit (avoiding the exit closest to the danger zone) requires longer egress time but can reduce casualty rate, and this finding is consistent with the conclusion drawn in [1]. Next, we examined the simulation data to identify the optimal emergency exit.

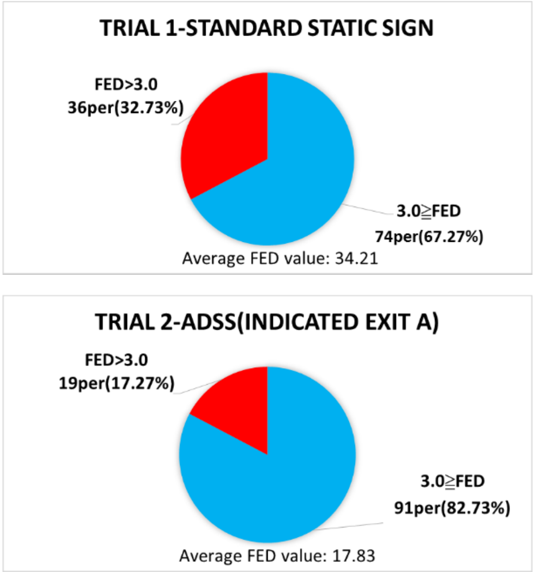

Fig.7. Trial 1 and Trial 2 FED pie chart

5 INVESTIGATION

For further discussions, this study conducted a simulation of ADSS-indicated exits B, C, and D to determine the effects of ADSS-selected exits on evacuees and explore whether an optimal exit can be obtained.

5.1 Effect of Exit Selection on FED

After a simulation of conventional signage systems and ADSS was completed, we used FDS to set the source of fire at an area near Exit C and simulated the scenario in which ADSS is used in Exits A-D as the emergency exit. The purpose was to determine the FED inhaled when evacuees choose to evacuate through different exits. Fig. 8 presents the simulation results, which show that when ADSS indicated evacuees to exit at Exit C, the FED cumulative value was substantially higher than that observed in other evacuation scenarios. In particular, 67.27% of evacuees registered FED of ≥3.0, which is approximately 3.89 times greater than that when ADSS indicated evacuees to exit at Exits A, B, and D. The average FED value was 91.20, which is more than five times greater than that when other evacuation routes were chosen. This result is possibly attributed to the fact that fire was ignited near Exit C. Therefore, if Exit C was the indicated exit, then the evacuees were guided to exit near the fire-burning site, which is the high-risk zone. In addition, the second highest average FED value was the result of using a conventional signage systems; the average FED value was almost twice that when ADSS was used to indicate Exits A, B, and D as the emergency exit.

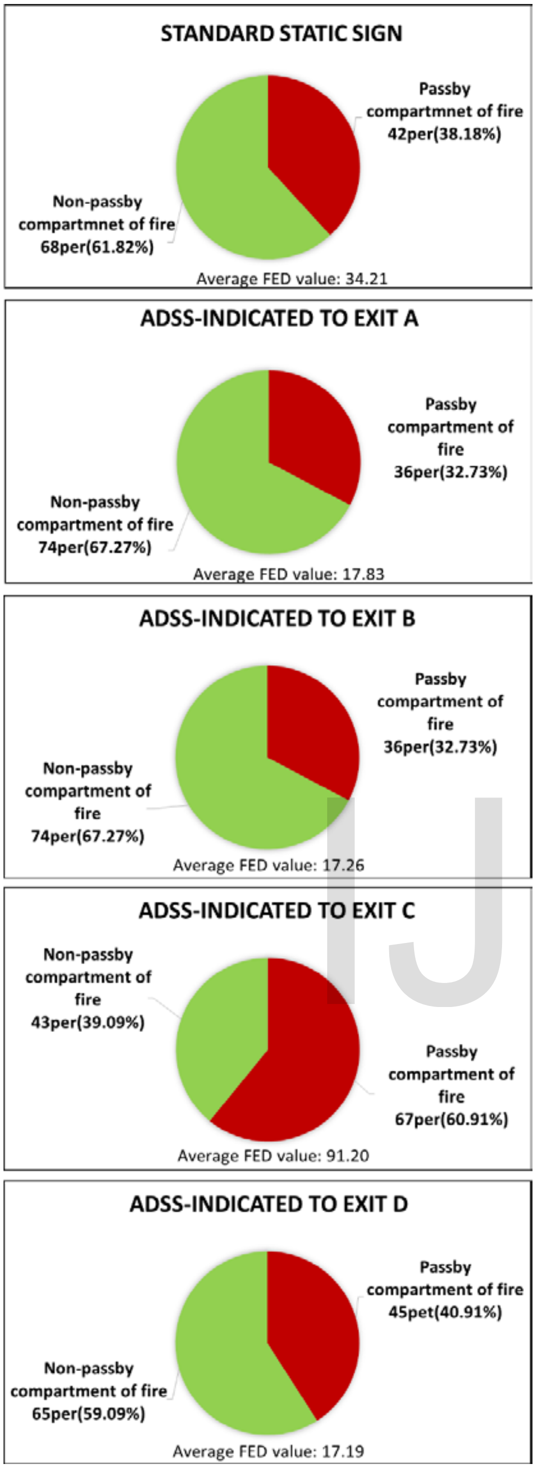

Fig.8. The number of people in various scenarios when FED≥3.0 and FED≤3.0

5.2 Safe Selection

To obtain a further understanding of the compartments along the evacuation route passing the source of ignition and their risk in causing severe casualties, we extended the aforementioned experiments, simulating four scenarios in which fire broke out at areas near Exits A to D. Each scenario has five modes (conventional signage systems, ADSS-indicated to Exit A, ADSS-indicated to Exit B, ADSS-indicated to Exit C, and ADSS-indicated to Exit D) to facilitate understanding the relationship between fire zone and exit selection. A total of 20 simulation results were obtained.

According to NFPA 921- 23.5 Mechanism of death [15] and NIST-Report on High-Rise Fireground Field Experiments [16], an oxygen level below 10%, fire temperature between 80°C and 120°C, and FED value greater than 3.0 pose an extremely high probability of causing fatality. Therefore, to determine the casualty situation in the 20 simulation results, we conducted statistics on the number of evacuees when FED is greater than 3.0, oxygen falls below 10%, and the temperature is greater than 80°C. Fig. 9 shows the results.

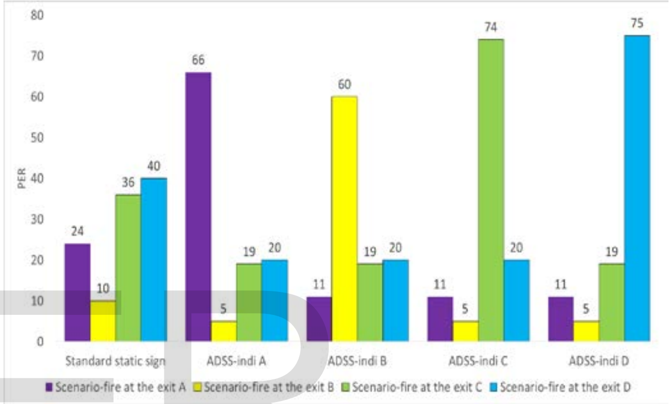

Fig.9. Number of evacuees at a high risk of death

Fig. 9 indicates that in the 20 simulation modes, the Scenario-Fire at Exit D resulted in the highest number of death (75 deaths) when the ADSS indicated evacuees to exit at Exit D, followed by Scenario-Fire at Exit C when the ADSS indicated evacuees to exit at Exit C (74 deaths). Overall, when ADSS guided evacuees to exit near the fire-breakout zone, evacuees are exposed to high risk of death. According to the number of evacuees at a high risk of death in the four fire scenarios, we found that except forthe number of death used by ADSS indicated the exit in fire, conventional signage systems mode was the highest. For example, when the fire broke out near Exit D, the number of evacuees at high risk of death was 40 with conventional signage systems, second to the number of death caused by Scenario-Fire at Exit D when ADSS indicated evacuees to exit at Exit D. (We deduced that guiding evacuees to the fire zone will result in severe casualties. Moreover, when conventional signage systems were used, because evacuees were guided to the nearest exit without avoiding the fire zone, evacuees may have entered high-risk zones by chance, causing higher casualty rates.)

Next, we divided evacuees into two groups according to the simulation data: “evacuees pass by compartment in fire” and “evacuees non-pass by compartment in fire”. Subsequently, average temperature, average oxygen level, average FED, and total egress time were calculated to infer the reason causing fatalities. Table 7 presents the statistical results, with bolded and italicized fonts representing "the indicated exit" as "the exit on fire".

TABLE7

AVERAGE TEMPERATURE, AVERAGE OXYGEN LEVEL, AND AVERAGE FED IN EACH SCENARIO (NOTE: BOLDEDFONTS REPRESENT "INDICATED EXIT" AS "FIRE EXIT")

	Scenario	Egress time	Evaluation Criteria	Initial fire location on exit A	Initial fire location on exit B	Initial fire location on exit C	Initial fire location on exit D	Average value
Pass by compartment of fire	Conventional Standard sign	204s	Average Temp(°C)	336.40	278.27	364.41	489.61	367.17
			Average Oxygen Concentration (%)	5.48%	5.90%	4.90%	6.30%	5.65%
			Average FED	76.39	107.50	102.77	34.64	80.33
	ADSS-Indicate to exit A	250s	Average Temp(°C)	**275.60**	163.28	208.81	190.84	209.63
			Average Oxygen Concentration (%)	**4.77%**	14.37%	11.96%	12.81%	10.98%
			Average FED	**139.49**	28.28	41.41	34.69	60.97
	ADSS-Indicate to exit B	250s	Average Temp(°C)	51.08	**227.20**	88.76	81.05	112.02
			Average Oxygen Concentration (%)	18.91%	**5.01%**	16.62%	17.04%	14.40%
			Average FED	15.60	**183.74**	33.24	30.06	65.66
	ADSS-Indicate to exit C	216s	Average Temp(°C)	194.32	198.67	**348.52**	163.45	226.24
			Average Oxygen Concentration (%)	12.62%	12.38%	**5.20%**	14.06%	11.07%
			Average FED	51.19	50.82	**129.93**	40.75	68.17
	ADSS-Indicate to exit D	234s	Average Temp(°C)	274.30	224.65	281.25	**473.25**	313.36
			Average Oxygen Concentration	12.61%	14.30%	12.52%	**5.30%**	11.18%
			Average FED	14.79	12.09	14.79	**58.19**	24.97
Non-pass bycompartment of fire	Conventional Standard sign	204s	Average Temp(°C)	20.15	20.14	20.34	20.27	20.23
			Average Oxygen Concentration (%)	20.78%	20.78%	20.78%	20.78%	20.78%
			Average FED	0.84	0.84	0.85	0.84	0.84
	ADSS-Indicate to exit A	250s	Average Temp(°C)	**20.15**	20.27	20.18	20.18	20.20
			Average Oxygen Concentration (%)	**20.78%**	20.78%	20.78%	20.78%	20.78%
			Average FED	**0.84**	0.96	0.88	0.88	0.89
	ADSS-Indicate to exit B	250s	Average Temp(°C)	20.15	**20.13**	20.16	20.16	20.15
			Average Oxygen Concentration (%)	20.78%	**20.78%**	20.78%	20.78%	20.78%
			Average FED	0.86	**0.83**	0.88	0.87	0.86
	ADSS-Indicate to exit C	216s	Average Temp(°C)	20.45	20.46	**20.33**	20.39	20.41
			Average Oxygen Concentration (%)	20.78%	20.78%	**20.78%**	20.78%	20.78%
			Average FED	0.93	0.94	**0.84**	0.88	0.90
	ADSS-Indicate to exit D	234s	Average Temp(°C)	20.36	20.37	20.32	**20.27**	20.33
			Average Oxygen Concentration (%)	20.78%	20.78%	20.78%	**20.78%**	20.78%
			Average FED	0.92	0.91	0.89	**0.84**	0.89

In summary, although use of conventional signage systems resulted in shorter egress time (based on nearest exit as the emergency exit), the simulation result indicated that if the scenario in which ADSS led evacuees directly to the fire zone, the risk values of average temperature, average oxygen concentration, and average FED were greater than those when ADSS was used. In addition, for evacueeswho non-pass by compartment in fire, the average temperature, average oxygen concentration, and average FED in each scenario were having more opportunity to survive. We can therefore infer that passing the compartment in fire along the evacuation route will cause severe casualties. Moreover, safe evacuation route planning should focus on choosing the route that minimizes FED inhalation, facilitates successful evacuation, and minimizes mortality rate, even if longer egress time results.

6 CONCLUSION

This study conducted software verification and simulation of real-life experimental data for conventional signage systems and ADSS. The following findings were obtained:

1. The Trial 1 and Trial 2 simulation results revealed that the safety of the evacuation route was more important to the overall evacuation speed on the premise that the FED inhaled by evacuees falls within the safe range. When Trial 1 (conventional signage systems) results were compared with Trial 2 (ADSS) results, we found that the conventional signage systems tended to guide evacuees to the nearest exit, and without considering the risk of the exit, the total egress time may be faster to the ADSS, which guides evacuees to the indicated exit. Concerning the FED accumulative values, Trial 1 values were almost twice Trial 2 values, implying that in actual situations, conventional signage systems may lead evacuees to danger zones (source of fire), thus resulting in severe casualties.

2. Passing the source of fire during evacuation is the key causing high FED accumulative value. Through ADSS simulation, different indicated exits and compartments can be selected to simulate evacuation route and collect fire disaster data. Subsequently, the possible casualties observed in various evacuation plans can be determined to identify the safest evacuation route. If ADSS can detect the source of fire in the building thus preventing evacuees from approaching danger zones, and if optimal escape route can be selected from a route simulation, then casualties can be effectively reduced and evacuation designs for a building can be improved.

3. Multiple simulation data can be applied in selecting emergency exits and planning safe routes for fire events. Analyzing the temperature, oxygen concentration, and FED of the fire-burning site facilitates determining the route that results in minimal casualties and mortalities and ensures high success rate in escaping from the fire zone.

In summary, inputting experimental data of evacuation signage system into simulation software can not only effectively reproduce evacuees' behavior in choosing exits, but also generate sizeable and useful data at a low cost. Moreover, using simulation software allows posthoc comparison or other environmental information to be incorporated and enables the use of computers to conduct automated statistical analysis. By operating evacuating simulation software, users can simulate building fire scenarios to quickly collate fire data and design fire prevention and evacuation plans for large, public areas. Furthermore, establishing safe evacuation route through simulation can effectively reduce the number of accidental casualties and strengthen public building safety. In future, digital technologies can be applied with more mature experimental data or accurate simulation software to include environmental variables into simulation setting. By doing so, significant indicators for planning optimal exits in cases of fire events can be acquired to facilitate accelerating research and development of signage systems and related fields.

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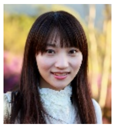

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