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Effects of computer and demonstration scenario simulation using smart fire evacuation guidance on evacuation induction and time

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스마트 화재대피 유도 컴퓨터 및 실증 시나리오 시뮬레이션이 피난 유도와 시간에 미치는 영향

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Abstract This study examined how the fire evacuation induction service system using a smartphone navigation application in the event of a fire affects the fire evacuation time, and the following conclusions were drawn. 1. The evacuation time was reduced by 22 seconds when the navigation application was used in computer scenario simulation. Even in the demonstration simulation, the evacuation time was reduced by 40 seconds when the navigation application was used. This indicates that the navigation application is effective in shortening the evacuation time in case of fire. 2. As a result of the demonstration scenario simulation, the time until the end of evacuation was 39 seconds faster in the case of evacuation guidance than in the case where it was not conducted. 3. No bottlenecks occurred in the evacuation route during the demonstration scenario simulation. As a result, there was a difference in the time required to complete the evacuation between the computer scenario simulation and the demonstration scenario simulation.

Key Words : Fire evacuation, Fire simulation, Scenario, Prevention awareness, System necessity

요 약 본 연구는 화재 발생 시 스마트폰 네비게이션 어플리케이션을 이용한 화재 대피 유도 서비스 시스템이 화재대피 시간에 어떤 영향을 미치는지 살펴보고자 하는 연구이다.
컴퓨터 시나리오 시뮬레이션에서 네비게이션 어플리케이션을 사용하였을 때 대피시간이 22초 단축되었고 실증시뮬레이션 또한 네비게이션 어플리케이션을 사용하였을 때 대피시간이 40초 감소되어 화재 발생 시 피난 시간 단축에 효과적이라는 점을 알 수 있다. 실증 시나리오 시뮬레이션을 한 결과는 피난유도를 실시한 경우가 실시하지 않은 경우보다 피난 종료까지 시간이 39초 더 빠르게 나타났다. 실증 시나리오 시뮬레이션은 피난 경로에 병목현상이 발생하지 않았고 이로인해 컴퓨터 시나리오 시뮬레이션과 실증 시나리오 시뮬레이션의 대피 완료 소요시간의 차이가 발생하였다. 추후 시나리오 시뮬레이션에 학생실습 연구에 기여할 것이다.

주제어 : 화재대피, 화재 시뮬레이션, 시나리오, 예방인지, 시스템 요구

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1. Introduction

The speed of a pedestrian is influenced by the psychological state (competitive or non-competitive)[1]. The direction of a pedestrian depends on the pedestrian's activity. If the purpose of the visit and the destination are the same, the direction of all pedestrians is the same. However, depending on the next choice of the crowd already moved to the destination, people will flow to other destinations, which may cause the safety issue. In the study of Simhasth, it was concluded that the walking speed of the crowd was within the range of speed from 0.8 m/s to 1.5 m/s, and the range distribution of walking speed in cities appeared to be larger in normal times [2].

Changing direction with the crowd during evacuation reduces the time to find routes and exits, but it causes the side effect of moving to the same space with the crowd. It has been observed that pedestrians in panic choose not to go to their destination, but rather to go to a high-density location. Crowd psychology can be identified as three components: personality, emotion, and atmosphere, and these are reflected in agent-based simulation. The behavior of the crowd is always determined emotionally, and fear and anger have a decisive influence. In particular, anger is the basic emotion of people in the crowd that is aggravated by the situation. Researchers have shown that emotions are contagious. Psychological characteristics and the level of psychological stabilization affect the safety of the crowd, and taking this into account is important to ensure crowd safety.

Panic stampedes are the most problematic and likely situations in evacuation situations during cluster accidents and disasters. In fact, despite many control measures in large-scale assembly, hundreds of cases of cluster accidents have occurred worldwide [3]. Therefore, a more realistic simulation tool should be developed that considers the characteristics of pedestrians, group behavior in emergency situations, crowd dynamics, and psychological aspects of the crowd.

Cellular Automaton models, network models, and fluid models identify variables such as density, walking speed, and traffic volume from a macroscopic perspective. Unlike this, the potential model and the magnetic model are models that can express even local parts. However, these walking models are performed under quite limited conditions, such as the direction of travel is limited as the space is subdivided. In addition, even in the case of a model that does not divide the space, there are few models that can express macro and micro movements in a space with multiple paths. Cellular Automata is known as a suitable tool for modeling patterns of various kinds of phenomena such as fluid flow, traffic flow, urban logistics or economic activity. That is, it is suitable for macroscopic simulation of complex systems. The general Cellular Automata, which is currently used to predict pedestrian flow, divides the space into grid regions. In addition, it simulates by changing the state of each cell according to a simple rule that determines the state of a cell at a time step according to the state of its neighboring cells. The rules are simple, but complex patterns can be formed by using multiple cells. The characteristic of this model is that it can qualitatively classify patterns and quantitatively grasp the overall image even if simple rules are used. Also, in the case of group walking, the temporal variation of the spatial distribution of variables such as density and walking speed can be investigated. The study on evacuation simulation in Korea began in the late 1980s.

Although the research was not actively conducted, a study was conducted to develop a theoretical model through a computer program by Won-young Choi (1988) [4]. It was in 1995 when computer evacuation simulation was used in the research field in earnest in Korea after Simulex developed by Tompson and Marchant of the University of Edinburgh in the UK was spread to Korea [5]. The software in simulating evacuation which are widely used for verification of indoor evacuation are Pathfinder, Steps, Simulex, Builngding Exodus, FDS+Evac and GridFlow which combines grid and continuous models.

The cognitive path that determines the evacuation behavior the fastest is the manipulatory action (compulsory evacuation guidance of building personnel), followed by smoke, flame, sound, smell, and smoke. In the case of manipulatory action and heat, the reaction occurs within 5 minutes, but observation of flames or smoke, listening to sound, and smelling may take up to 6-10 minutes or more [6].

Not all people exhibit the same behavior patterns in a fire or disaster situation. It is known that the behavior pattern varies according to age, gender, education level, prior experience, and cultural influence. It is important to understand these factors that act as real problems in an evacuation situation [7]. Physical ability, such as walking speed, is one of the important factors at the individual as well as group level. When evacuating as a group, it is the presence of the weakest and slowest person that affects how fast the movement takes place. In addition, factors that hinder movement due to fire suppression or observation also slow down the speed, and changes in speed also occur depending on how well the crowd knows the structure and route of the building [8].

Individual walking speed in a crowd depends on density and distance from the person ahead. The walking speed decreases as the density increases and the distance decreases [9]. According to the study of human behavior in the movement stage, the results of the investigation on whether the exit sign affects the evacuation performance of people are as follows. People without experience and knowledge of buildings did not focus on signs at all, and people were divided into two types: those who trust only instincts and those who only use signs. Naturally, the evacuation speed of those who had knowledge of the building in advance and used the sign appeared the fastest [10]. Computer simulations have been used to demonstrate that a group of individuals with insufficient information can be directed to a target location by a small number of group members who have obtained the information. It was also said that individuals in a crowd, driven by a small number of information, could reach a consensus decision without knowing whether they belong to a majority or a minority, or whether the information collides with other sources of the group [11].

Recently, as fire disaster response has emerged as a social issue, intelligent fire detectors are drawing attention as an alternative to secure a golden time for evacuation. In particular, it is possible to escape from the risk of fire more quickly through the IoT communication network. Recently, research activities to develop firefighting products into a more intelligent and active system by introducing IoT technology, which is widely applied in most industrial fields, to the firefighting industry are being actively conducted. By automatically distributing sensor information to the network server through the

IoT communication network, it is possible to prevent delays in reporting due to the absence of witnesses. In other words, it overcomes the limitations of wired installation and operation by using IoT-dedicated wireless communication. This has been evaluated as maximizing the efficiency of stable data transmission and system management [12, 13].

2. Related Works

Existing IOT fire notification service had a system that only informs the place of fire through a detector when a fire occurs [14, 15]. In the case of an evacuation route guidance system using an IOT smart fire alarm, the evacuation route was guided using a notice board installed next to the signboard. However, in the event of a fire, there was a problem that the notice board for evacuation routes was not visible due to smoke.

Therefore, it is required to develop a platform responding to a fire situation. Then it can support evacuation while monitoring the fire situation in real time and predicting the area where a fire may occur in the event of a fire. Also, there is an urgent need for an application that can monitor fires in real time and direct evacuation directions by developing a real-time fire monitoring technology based on sensors. In this research, a computer simulation is conducted to inform the fire point using a smartphone navigation application, and to enable efficient evacuation to an emergency or evacuation area without being crowded to one place. Therefore, we tried to see how the fire evacuation induction service system using a smartphone application affects fire evacuation.

3. Proposed Method

This study consists of computer scenarios simulation and demonstration scenario simulation.

3.1. Computer simulation

To review the safety of evacuation and the appropriateness of the application of evacuation means, a computer simulation was conducted under the conditions with or without evacuation guidance in case of fire.

3.1.1. Summary

- Target space : Simulation was performed at the D Promotion Agency located in C-si, K-do. The building area is 4,554.18 m², with 4 stories below the ground and 8 stories above the ground. The first floor is an exhibition facility, and the second to seventh floors are business facilities. program and the number of people in simulation : Simulex is a program based on the Cellular Automata model, which is used for macroscopic simulation of complex systems such as fluid flow and traffic flow. In disposing people, the population density was set to 9.3㎡/person based on business facilities. The walking speed was set to 1m/s~1.2m/s, which is the horizontal average moving speed of adult men and women, and the number of experimental people was set to 1,719. Fig.1 shows disposition of people using the Simulex program. The number of people disposed on each floor is 142 people on the 1st floor, 240 people on the 2nd floor, 278 people on the 3rd floor, 253 people on the 4th floor, 282 people on the 5th floor, 266 people on the 6th floor, 144 people on the 7th floor, and 147 people on the 8th floor.

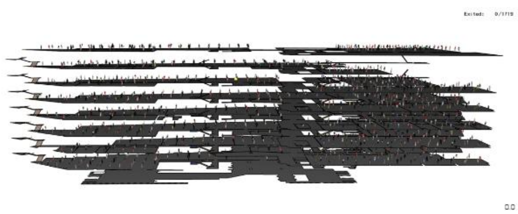

Fig.1. Disposition of people using Simulex program

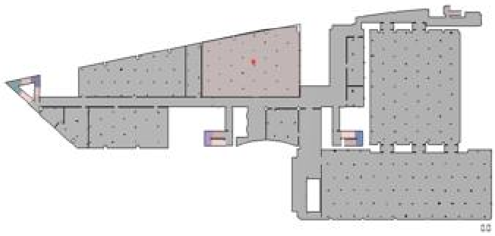

Fig. 2 Disposition of people on the 6th floor where the fire occurred

3.1.2. Space to be simulated

Fig.2 is a plan view of the 6th floor where a fire occurred and shows the arrangement of 233 people when set to 9.3㎡/person.

3.1.3. Scenarios of evacuation

- Case 1 : "After a fire breaks out, evacuation begins in the fire room (6th floor), and after 60 seconds, people on other floors except the 6th floor begin evacuation. Residents evacuate in a direction where it is judged that the route to the exit is close."

※ Do not intervene in the evacuation simulation, and people evacuate according to the evacuee's attribute values preset in the simulation.

- Case 2 : "After a fire breaks out, evacuation begins in the fire room (6th floor), and after 60 seconds, people on other floors except the 6th floor begin evacuation. The people receive guidance on the evacuation route through a fire detector and evacuate through an evacuation route where smoke has not spread."

※ The evacuees do not evacuate according to the evacuees' attribute value but evacuate through a evacuation route recognized in advance or after a fire.

3.2. Demonstration scenario simulation

3.2.1. Research subjects

In this experiment, 80 3rd grade students of K University Emergency Rescue Department in C area participated. The experimental place was the Korea Institute of Design Promotion. The case where evacuation was not induced and the case where evacuation was induced using the smart fire evacuation guidance service system was compared. 80 people were placed on the 6th floor, and the study was conducted when consent was obtained from the subjects before the study.

3.2.2 Research tools

- Smart fire evacuation guidance service system : In this study, a fire evacuation route guidance service developed by LDT located in C-si, C-do was used. The service consists of an early fire detector, a fire information relay device, a control system monitoring a fire / evacuation situation and a client app that guides evacuation.

In the event of a fire, the fire is recognized through the early fire detector, and the fire is reported to the server through the fire information relay device. After that, the client app for the evacuation guidance notifies the occupants of the building that a fire has occurred and guides the nearest emergency exit from the fire point.

3.2.3. Process of evacuation scenario

If a fire breaks out in the interior space, the fire detector detects the fire and enters the information of the fire room on the floor plan as shown in Fig. 3. An evacuation route is guided to people using a navigation app as shown in Fig. 4, and people are evacuated along this evacuation route as shown in Fig. 5.

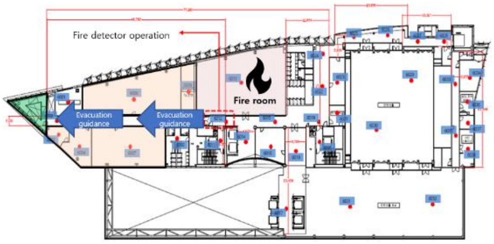

Fig. 3. Floor plan of evacuation guidance in case of fire

Fig. 4. Guidance of evacuation routes using the navigation app on the smartphone

Fig. 5. Evacuation using a navigation app in a smartphone

3.3. Analysis methods

To find out if the experience of demonstration simulation affects the evacuee guidance and time of evacuee guidance, the difference before and after the experiment was compared using the paired t-test of SPSS 21.0. The statistical significance level α was set to .05.

4. Experimental Results

4.1. Results of computer scenario simulation

The results of computer simulation of scenarios are shown in Table 1. If the evacuation guidance was not conducted, it took about 13 minutes 19 seconds (799 seconds) from the fire to the end of the evacuation. In the case of evacuation induction, it took about 12 minutes 58 seconds (788.3 seconds) after the fire occurred to complete the evacuation. In the floor where the fire occurred, no significant difference was found in terms of time reduction. When evacuation guidance was not conducted, the use of the farthest emergency exit was small. While the crowd was dispersed to the farthest emergency exit when evacuation guidance was performed. As a result of evacuation simulation on all floors, when evacuation guidance was applied, the number of evacuees decreased slightly until 210 seconds after the fire occurred (150 seconds after the start of evacuation). This is because there is no effect of evacuation guidance until then or the effect of guiding to a safe emergency exit farther than the nearest exit is reflected. However, after 360 seconds, the overall evacuation rate showed a difference of at least 1% to a maximum of 4%, confirming the evacuation induction effect. It is estimated that the effect of evacuation induction occurred after 360 seconds as occupants on floors other than the fire floor evacuated by stairs without competition with people on the fire floor who initiated evacuation in advance.

Table 1. Results of computer scenario simulation (N= 1,719)

Time (sec)	Number of evacuees by scenario			
	CASE 1		CASE 2	
	Num	Rate	Num	Rate
90sec	22	1%	22	1%
360sec	801	47%	806	47%
690sec	1554	90%	1609	94%
778sec			1719	100%
799sec	1719	100%		

4.2. Results of demonstration scenario simulation

Results of demonstration scenario simulation are shown in Table 2. In the case of evacuation guidance using the smart fire evacuation guidance service system, it took about 6 minutes 14 seconds (374 seconds) to complete the evacuation after the fire occurred. When evacuation guidance was not conducted, it took about 6 minutes 53 seconds (413 seconds) from the fire to the end of the evacuation. As shown in Table 3, in the case of evacuation induction, the time to the end of evacuation appeared faster than in the case of no induction, and there was a statistically significant difference ($p < .001$).

Table 2. Results of demonstration scenario simulation (N= 1,719)

T i m e (sec)	Number of evacuees by scenario			
	CASE 1		CASE 2	
	Num	Rate	Num	Rate
180sec	8	10%	18	23%
360sec	51	64%	72	90%
374sec	63	79%	80	100%
413sec	80	100%		

Table 3. Comparison of evacuation time according to evacuation guidance in demonstration scenario simulation (N= 1,719)

	M ± SD	Min	Max	F	p
with guidance	256±32	137	374	1.52	.000***
without guidance	302±18	158	413		

5. Discussion

This study considered the cases of inducing and not inducing evacuation in the event of a fire and used a fire evacuation route guidance service developed by LDT located in C-si, C-do. The program used was a computer scenario simulation based on the Simulex, the Cellxular Automata model. The demonstration scenario simulation was conducted at the Korea Institute of Design Promotion in S-si, K-do with 80 third-year students of the Department of Emergency Rescue at K University in C area.

When evacuation guidance was applied, the number of evacuees decreased slightly until 210 seconds after the fire occurred (150 seconds after the start of evacuation). This is because there is no effect of evacuation guidance until then and the effect of guiding to a safe emergency exit farther than the nearest exit is reflected. The characteristic of crowd's decision-making like this needs to be considered especially in emergency evacuation situations where only a small number of members of the crowd have information. In other words, it is considered that crowd flow can be controlled through the placement of people who are aware of the emergency exit location or evacuation route.

However, after 360 seconds, the overall evacuation rate showed a difference of at least 1% to a maximum of 4%, confirming the effect of evacuation induction. It is estimated that the effect of evacuation induction occurred after

360 seconds, as occupants on floors other than the fire floor evacuated by stairs without competition with people on the fire floor who initiated evacuation in advance. Rather people were guided to the nearest emergency exit or following the evacuee attribute value of an evacuation simulation that applies a tracking instinct, but forcibly guided to a safe emergency exit that is not affected by fire, the time required to evacuate from the entire building has been shortened.

In the previous study, when a passage of 2m in width and 10m in length connects two rooms of 10m in width and length, it took about 204 seconds for 100 occupants to reach the safe area in the case of an evacuation situation where only static hazards exist. It was confirmed that as the number of people increased, the flow of persons decreased. This phenomenon seems to have occurred because of separation during the movement of the crowd to maintain the minimum distance between people [16].

The result of a demonstration scenario simulation by conducting evacuation guidance using the smart fire evacuation guidance service system, it took about 6 minutes 14 seconds (374 seconds) to complete the evacuation after the fire occurred. When evacuation guidance was not conducted, it took about 6 minutes 53 seconds (413 seconds) from the fire to the end of the evacuation. In the case of evacuation induction, the time to the end of evacuation appeared faster than in the case of no induction, and there was a statistically significant difference ($p < .001$). In terms of speed of evacuation reaction, the general cognitive path that determines the evacuation behavior the fastest is the manipulatory action (compulsory evacuation guidance of building personnel), followed by smoke, flame, sound, smell, and smoke. In the case of manipulatory action and heat, the reaction occurs within 5 minutes, but observation of flames or smoke, listening to sound, and smelling may take up to 6-10 minutes or more [6]. In a previous study comparing evacuation speed according to evacuation knowledge in case of fire, it was found that the group with knowledge took an average of 79 seconds to complete evacuation, and the group without knowledge was 92.7 seconds, which indicated that the group with evacuation knowledge quickly evacuated [17]. Although it is not the same experiment as this study, the results of the demonstration scenario simulation support that the time to the end of evacuation was 39 seconds faster in the case of evacuation guidance than in the case where it was not conducted. The previous studies like computer simulation of fires in day care centers [18], fire target simulation in subway platform [19], and fire simulation in a road tunnel [20] calculated evacuation times according to the simulation, but they did not verify whether there is any statistical difference. For this reason, it was limited in comparison with the statistical significance calculated by computer simulation in this study.

According to one previous study, in a single-story building, several people evacuate toward one exit, and 72 people try to proceed in the same direction through a narrow passage. So, there are a lot of differences between the distances traveled among people [21].

A fire simulation of apartment houses (6 floors in a 25-story building) confirmed that people must evacuate within 140 seconds from the fire room, while within 235 seconds from the non-fire room, and all occupants should evacuate through the evacuation stairs within 200 seconds [22].

Nevertheless, there were some limits in this study. This study used the paired t-test. So, it would be too simple to explain the results of the crowd psychology.

This study examined how the fire evacuation induction service system using a smartphone navigation application in the event of a fire affects the fire evacuation time, and the following conclusions were drawn.

1. The evacuation time was reduced by 22 seconds when the navigation application was used in computer scenario simulation. Even in the demonstration simulation, the evacuation time was reduced by 40 seconds when the navigation application was used. This indicates that the navigation application is effective in shortening the evacuation time in case of fire.

2. As a result of the demonstration scenario simulation, the time until the end of evacuation was 39 seconds faster in the case of evacuation guidance than in the case where it was not conducted.

3. No bottlenecks occurred in the evacuation route during the demonstration scenario simulation. As a result, there was a difference in the time required to complete the evacuation between the computer scenario simulation and the demonstration scenario simulation.

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