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Research paper

Intelligent Evacuation Guidance for Fire Response in Super High-rise Buildings

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Abstract

Recently, urban structures including buildings are becoming increasingly large and super high-rise making human life more convenient. As the number of super high-rise buildings increases, the risk of fire and other disasters is also increasing. Deaths and injuries would be tremendous than imagined if the evacuation guidance would not be provided promptly and precisely for the occupants in case of a fire in super high-rise buildings. Therefore, rapid rescue should be done for those who are in need of immediate assistance or rescue in the building. In this paper, the proponents propose a method for intelligent evacuation guidance by deriving the optimal evacuation route based on the fire location. To do this, a simulation and modeling method is also being proposed for calculating the optimal evacuation route based on the fire location, the number of residents and evacuation speed information when a fire occurs in super high-rise buildings. For this to happen, the evacuation type that is suitable for building type and resident characteristics must first be extracted through the evacuation simulator. If a fire actually occurs, evacuation proceeds according to the scenario extracted through the simulator. When the evacuation starts, the location information and the evacuator speed information are being collected in real time. Using this information, a modified evacuation route that can shorten the evacuation time would be obtained using the evacuation route change condition formula. Also, the location-based evacuation model informs residents of the optimal evacuation route and provides firefighters with location information of residents. This study models the optimal evacuation method for super high-rise buildings by simulating the evacuation type selection and implementing the evacuation route change condition formula using the location information collected in real time. Finally, the location-based evacuation model consists of the location identification technique required to derive the evacuation route and the optimal evacuation route calculation based on the resident's location information.

Keywords: *Dynamic Disaster Response based Real-time Information, Evacuation Guidance Type, Evacuation Route, Evacuation Simulation, Location Identification*

1. Introduction

With the rapid increase in the population of the city due to industrialization, the buildings are increasingly becoming larger and more complex [1][2][3]. Also, as the size of the buildings grows, there are many floating populations besides the existing residents. If social disasters such as fires occur in high-rise or large-scale buildings, large-scale casualties and social losses could be expected to occur. Therefore, in the event of a major disaster such as a fire, it is necessary to quickly identify the occupants in the building, and then provide rapid evacuation guidance.

In general, disaster types are classified as natural disasters such as typhoons and floods, and social disasters such as terrorism and facility collapse. While natural disasters can be predicted in advance, social disasters are difficult to predict. Disaster management requires staged activities such as preparation, response, and recovery. The preparation stage focuses on activities such as evacuation message dispatch and announcement inspection before a disaster occurs, and the response stage mainly carries out activities to rescue the victims. The recovery stage performs the overall recovery procedure after the disaster ends.

When a fire occurs in super high-rise buildings, quick initial response is essential in order to minimize the casualties. In case of a fire, the alarm sounds and the evacuation announcement is broadcasted, however, evacuation may become difficult because residents cannot easily understand the evacuation situation in super high-rise buildings. To solve this problem, it is necessary to use location identification technology in order to identify residents in buildings, the size and the location of the people inside the building for the quick evacuation guidance.

In super high-rise buildings, generally, residents may be restricted by autonomous behavior due to a limited space and when a disaster such as a fire occurs, it may become difficult for residents to make a reasonable choice due to limited information and space. If the residents of high-rise buildings receive the optimal evacuation route in the event of a fire, then the evacuation time will be shortened effectively. In order to achieve this goal, research on a location-based evacuation model is needed.

Researches have been conducted on large-scale disasters such as fires. There was a study that implemented an escape route search algorithm in the event of fire or terrorist attacks [4], and a study that proposed an evacuation guidance algorithm using mesh routing in high-rise buildings [5]. Also, there are researches related to a real-time evacuation guidance system using a variable induction device in case of an underground space fire [6], and a study that suggests an evacuation simulation system that can be used in actual disaster situations [7]. One of the most represented international studies was focused on the investigation of terrorism in the US World Trade Center [8]. In this study, 30 items were proposed in relation to the protection of fire in super high-rise buildings.

In this paper, an efficient evacuation guidance method when a disaster such as fire occurs in super high-rise buildings will be studied. This study proposes the simulation and modeling method in order to calculate the optimal evacuation route based on the fire location, the number of residents and evacuation speed information. In order to extract the scenarios that can be used in real fire, the type of evacuation which is suitable for the building type and the resident characteristic was extracted through simulation. Also, the modeling of the optimal evacuation method was performed for super high-rise buildings by simulating the evacuation type selection and implementing the evacuation route change condition formula using location information that was collected in real time.

The rest of this paper is organized as follows. Section 2 discusses the evacuation model based on location identification. The existing evacuation model presented in the previous studies was analyzed, and then an evacuation model was suggested based on real time location information. In Section 3, the evacuation modeling based on simulation was proposed. Also, evacuation type derivation for safe and rapid evacuation was performed by using evacuation simulator based on building information and resident information. In Section 4, the evacuation simulation was performed using the Pathfinder, an evacuation simulator, and then the simulation results were analyzed. Section 5 concludes this paper and proposes the future research.

2. Location-Based Evacuation Model

Although the probability of a fire in high-rise buildings is low, the damage can be very large. Moreover, it is difficult to find evacuation routes because there are usually too many residents in the narrow spaces of high-rise buildings. Also, when residents evacuate for a long time in a closed space such as an emergency staircase, psychological anxiety and physical problems may occur. Due to the complexity of high-rise buildings, it is difficult to predict the propagation path of the flame and to understand the situation for evacuation and rescue. In case of a fire in high-rise buildings, rapid initial response and evacuation are necessary to minimize the casualties.

Evacuation in high-rise buildings may become inefficient when residents have to encounter many difficulties in identifying the evacuation situations. To solve these problems, location identification techniques can be used to guide the residents to evacuate to routes leading to stairs and emergency exits that were less crowded [9]. Also, CCTV image analysis algorithms can be applied to reflect the evacuation route by collecting evacuation area information through visual distance detection [10][13]. Using these techniques and algorithms, this paper proposes an optimal evacuation model for evacuation type selection and evacuation route derivation when a fire occurs in high-rise buildings.

2.1. Existing Evacuation Model

Fig. 1 shows the existing methods and procedures for responding to fire when it occurs. As shown in the figure, in the existing evacuation model for high-rise buildings, fire alarm and evacuation announcement broadcast were uniformly performed in case of fire. Therefore, bottlenecks can occur because residents in the floor on fire and the adjacent upper floor have to evacuate urgently while the residents of the other floors could be evacuated simultaneously.

Utilizing the existing evacuation models can be dangerous because it prevents emergency evacuation in a way that does not consider evacuation priorities. Even if a sequential evacuation method would be adapted, uniform evacuation would be performed at a designated evacuation sites that were independent of the location of the fire. This does not take into account the spread of flame or smoke due to the fire, hence evacuation of residents could lead into dangerous areas with a worst case. Also, there is no way to disperse residents when they are concentrated in a particular area.

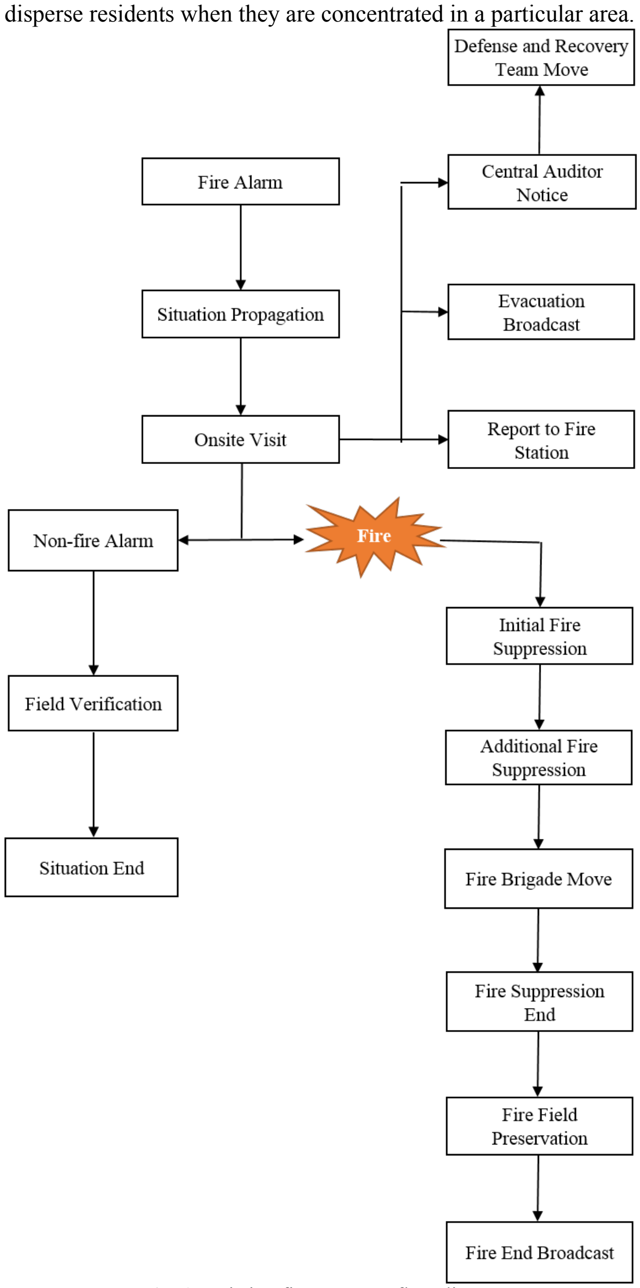


Fig. 1: Existing fire response flow diagram

2.2. Location-Based Evacuation Model

In order to construct the evacuation model based on location identification, the existing disaster prevention system should be integrated with the location identification technology. Location identification technology uses beacons, mobile devices, etc., to provide information for finding intelligent evacuation route [11][12][15]. In order to find intelligent evacuation routes, the evacuation type that reflects the characteristics of the building and resident should be selected through simulation. This is to ensure the safety of the first principle in evacuation.

The type of evacuation selected through simulation is reflected in the disaster prevention system, and utilized to inform the evacuation method and priority according to the location of the fire. In the process of evacuation, the evacuation route change condition

should be searched so that rapid evacuation can be achieved by analyzing the real-time location information and evacuation speed of residents. In CCTV image analysis algorithms, information on unavailable areas should be reflected in the evacuation route change conditions, and changes to existing evacuation routes must be made. When applying an evacuation route change, the evacuation route that reflects the inhabitable zone should take precedence. The modified evacuation route can be guided through the IP speakers installed on the floor and resident's mobile devices.
Information on residents collected in real time would be applied to evacuation route change conditions to improve the evacuation density which indicates the concentration degree of residents during evacuation. By applying the evacuation density, it is possible to shorten the evacuation time and to identify the remaining people to help the rescue activities. The evacuation model based on location identification should utilize the location information of the fire, the fire situation, and the evacuation situation of the occupants. To realize this model, beacons and mobile devices for locating residents, IP speakers for customizing broadcasts, CCTVs and image analysis algorithms for finding inhabitable areas should be added to the existing fire protection system. The following figure shows the system configuration diagram for constructing the evacuation model based location identification.

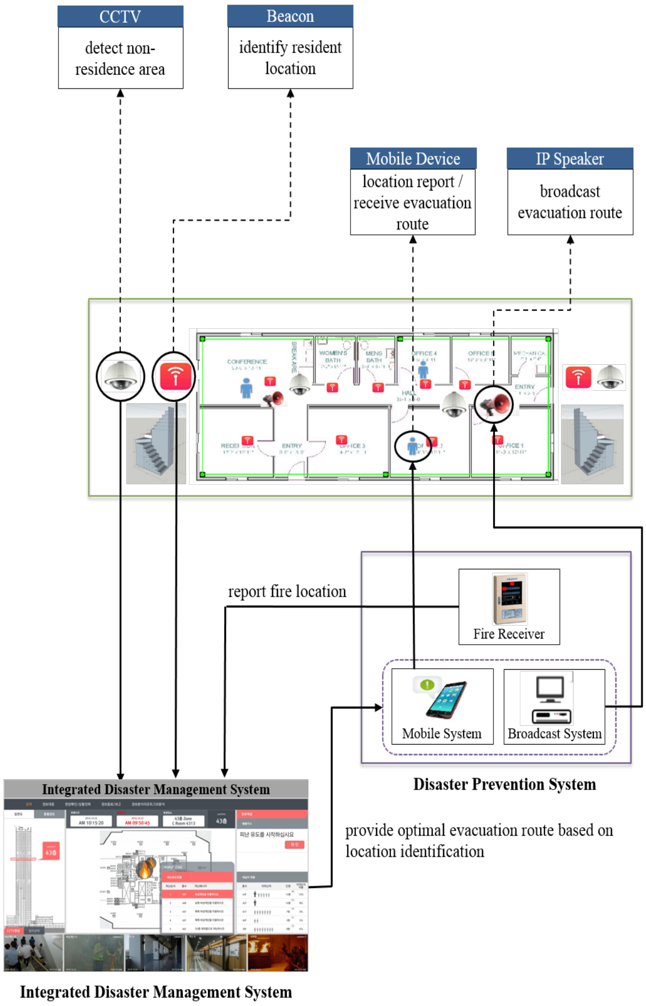


Fig. 2: System configuration diagram for the evacuation model based on location identification

The following figure shows the procedure for responding to the fire situation using the evacuation model based on location identification. Basically, various types of evacuation can be applied depending on the various situations of fire occurrence. These evacuation types such as whole floor evacuation, sequential evacuation, etc., will be explained in detail later. It is an advantage that the evacuation types according to each situation can be applied in combination.

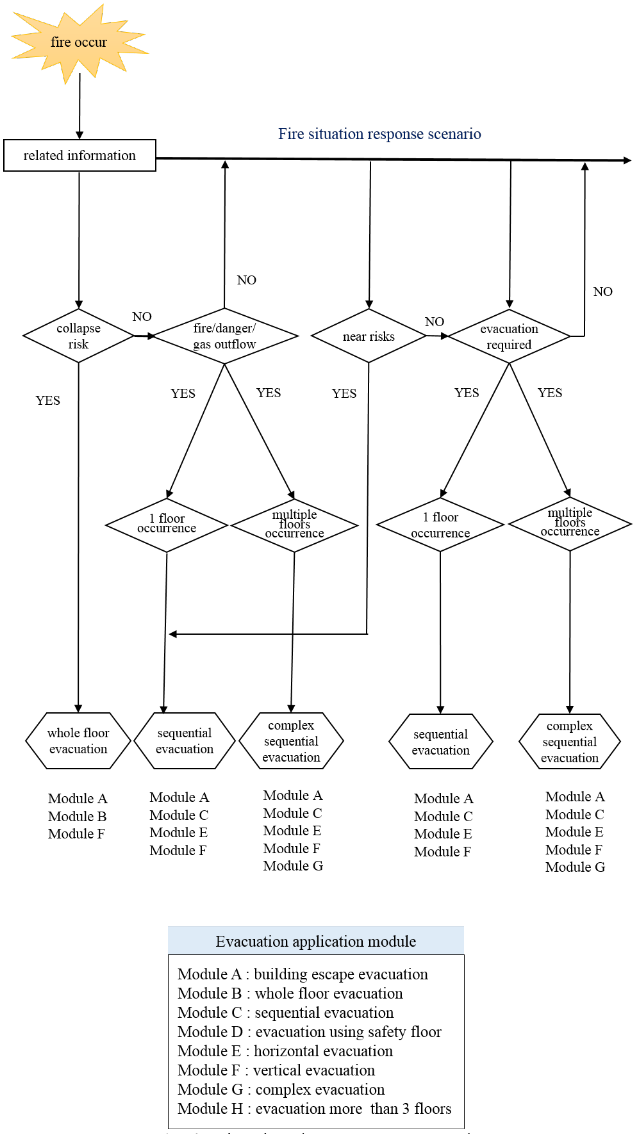


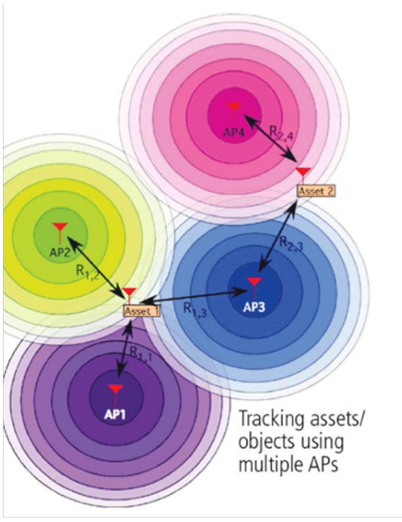
Fig. 3: Fire situation response procedure

3. Required Technology for Location-Based Evacuation Model

In order to realize the location-based evacuation model, necessary technologies such as location identification, mobile situation propagation, and system interworking are required. This chapter focuses on the major required technologies for implementing location based evacuation models.

3.1. Location Identification Technology

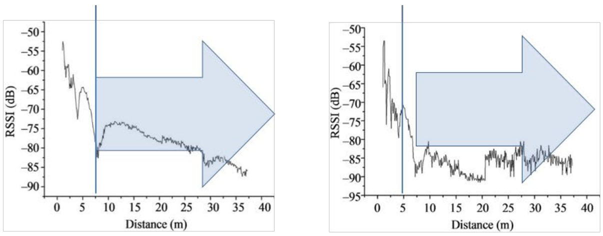
A key factor in constructing an evacuation model in the event of a fire is to locate the residents. In this study, a location identification technology that applies on beacons and mobile was used to locate the occupants in the building. In order to determine the position of the occupant, the indoor space would be divided into cells of a certain size, and the position would be determined by using the signal strength, signal pattern, signal delay, etc., received from the occupant's mobile device. At this time, it is important to determine the appropriate cell size by analyzing the correlation between the number of beacons and the accuracy of placement and position identification. It is also necessary to install a beacon in the escape stair or at the entrance of the evacuation area as well as indoors in order to monitor the status of the evacuated personnel. Therefore, beacons can be used to identify the number of people inside the building and the number of people that were evacuated. In addition, information obtained through the beacon can be transmitted to the firefighter in real time, thereby helping the rescue operation. The following figure shows the beacon signal test results for location identification.



signal strenth (dbm)	distance
-51 dbm	1m
-59 dbm	2m
-61 dbm	3m
-70 dbm	4m
-75 dbm or more	5m or more

result of signal measurement (average)

- use the principle that the distance of the beacon is inversely proportional to the signal strength
- Mobile apps keep track of beacon signal strength in the background
- determine the beacon position on the strong side of the signal through the signal intensity sampling for a short time

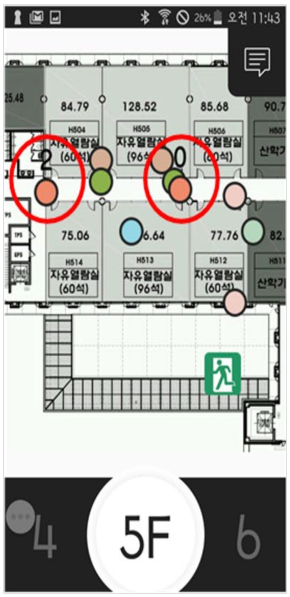


- Since the RSSI differs in measurement value depending on the measurement or the sensitivity of the measuring and the direction of the measuring device, a value of -80 dbm or more is not taken.

Fig. 4: Beacon signal test results for location identification

3.2. Mobile Technology

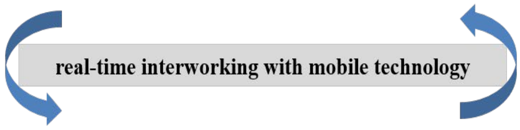
Mobile is becoming a universal means of communication in modern society, so mobile technology could play a very important role in rescue operation during disasters. Almost everyone has a smartphone nowadays and is carrying it like part of their body, especially inside a residential building. In a fire incident, it is essential to inform the residents and firefighters of the real-time information related to the fire situation in order to evacuate effectively. To do this, in this paper, two separate types of mobile apps were developed for residents and firefighters.
Resident's apps and firefighter's apps work effectively with escalation by providing real-time fire information in conjunction with the integrated disaster management system.
Information on resident location, fire propagation, smoke spread, and non-resident areas are transmitted in real time to the firefighter app. On the other hand, the resident's app guides the residents in an optimal evacuation route in real time. The following figure shows the execution screen of the mobile app for firefighters while updating in real time the integrated disaster management system.



mobiel application

- cell refers the vicinity of the location where the beacon is installed
- the current cell is composed of 3.5m radius

- the number inside the red circles indicates how many people are currently in the cell
- when move a smartphone with a mobile app, the number of people is updated every time in the cell



- the number inside the red circles indicates how many people are currently in the cell
- the number in the red dotted circle indicates the total number of people in the current floor

integrated disaster management system

Fig. 5: Execution screen of the mobile application

3.3. CCTV Technology

CCTV (closed-circuit television) is generally used as a device to monitor the current situation. CCTV is already a common monitoring device, and it is essential to link with existing CCTV in order to efficiently guide evacuation route. In addition, the intelligent CCTV is an enhancement of the existing CCTV and can provide various functions such as heat detection, smoke detection, flame detection function and personnel count.
In this study, intelligent CCTV connected with stereo camera was installed and used for counting the number of evacuees and evacuation speed measurement. Information on the number of evacuees and evacuation speed identified in real time will be used to guide intelligent evacuation by effectively distributing evacuess and thereby making the evacuation safety and efficiency. The following figure shows a screen to monitor the evacuation situation through the CCTV installed in the emergency stairs. Also, this figure shows the number of evacuees and density of people through intelligent CCTV with stereo camera.

- evacuation monitoring through CCTV installed at emergency stairs
- wired or wireless CCTV available

- accurate identification of the number of evacuees using a stereo camera
- people counting through CCTV image analysis analysis
- identification of people density of emergency stair by measuring movement speed

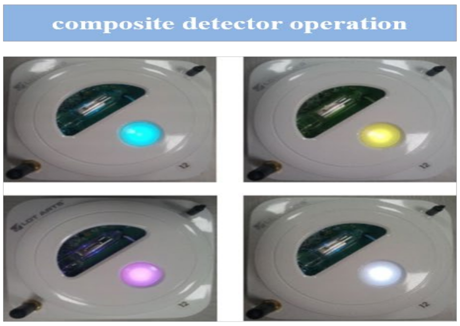
Fig. 6: General CCTV and intelligent CCTV interlocking screen

3.4. Complex Sensing Technology

Basically, it is essential to detect flame, smoke and temperature to cope with fire. To do this, it is more efficient to use an integrated composite detector than to use several sensors separately. In this paper, the proponents had used a gateway, repeater, and sensing node to utilize the complex detector which can detect flame, smoke, and temperature at the same time.

Using this composite detector, fire can be detected through flame or smoke detection first. In addition, complex detectors can identify non-residential or hazardous areas using temperature profiles sensed in real time. This information can be used to prevent residents from moving into hazardous and non-residential areas when evacuating. The following figure shows the configuration and operation status of the composite detector.

- detection sensor capable of sensing flame, smoke, and temperature
- gateways, repeaters and sensing nodes



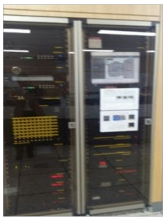
- top right (smoke & flame)
- top left (dlame & temperature)
- bottom right (temperature & smoke)
- lower left (flame & temperature & amoke)

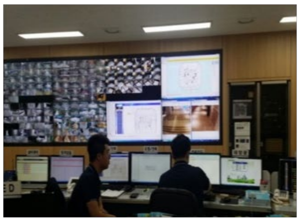
Fig. 7: Composite detector configuration and operation

3.5. Fire Receiver Interfacing Technology

The fire receiver provides the most basic information on the fire situation when a fire occurs. Since the fire receiver is enforced by law to be installed in buidings, it can be utilized by linking the fire receiver to collect information related to fire. Information related to firefighting equipment collected in real time from a fire receiver, such as sprinkler operation, fire door operation, and fire shutter operation, can be effectively utilized in evacuation route guidance. The following figure shows equipment related to the fire receiver and details for interfacing with the fire receiver.

firefighting facilities





FMS equipment R-type fire receiver disaster prevention center

details of interfacing the fire receiver

명칭	크기(byte)	Data Type	설명
Start	1	Char	문자열 'A'
Size	1	byte	데이터 길이
LType	1	Unsigned Char	이벤트 종류
LOG_MAX_DATETIME	6	Unsigned Char	이벤트 발생시간
LOn	1	Unsigned Char	동작 유무(숫자)
PANEL	2	Char	수신기 번호
LOG_MAX_MAPADDR	8	Char	주소
LOG_MAX_AREA	21	Char	구역
LOG_MAX_DEVICE	23	Char	장치
LOG_MAX_RUNNING	9	Char	동작 문자열

protocol structure

명칭	byte	HEX값	변환값	비고
Start	1	41	A	문자열
Size	1	48	72	숫자
LType	1	06	6	숫자
LOG_MAX_DATETIME	6	0C 04 1A 11 2D 0E	12 4 26 17 45 14	숫자
LOn	1	00	0	숫자
PANEL	2	30 31	0 1	문자열
LOG_MAX_MAPADDR	8	30 31 30 30 30 31 31 00	0 1 0 0 0 1 1 0	문자열 맨 끝 빨간색0은 무시
LOG_MAX_AREA	21	42 35 44 2D 4E B5 BF C0 FC 00 00 00 00 00 00 00 00 00 00 00 00	B5D-N동전	문자열(euc-kr)
LOG_MAX_DEVICE	23	50 2E 41 4C 2E 44 45 54 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00	PAL.DET	문자열(euc-kr)
LOG_MAX_RUNNING	9	C7 D8 00 00 00 00 00 00 00	해	문자열(euc-kr)

actual packet configuration

4148060C041A112D0E00303130313030303131004235442D4EB5BFC0FC000000000000000000
000000502E414C2E44455400000000000000000000000000000C7D800000000000000

actual packet

- implement the corresponding header structure in the interface module (TCP / IP connection)
- configure total protocol length to 73 Bytes

Fig. 8: Details of interfacing the fire receiver

3.6. Experiments Using Required Technology

In order to verify the applicability of the required technologies described in the previous section to actual evacuation guidance, experiments had been conducted. For the experiment, beacons, intelligent CCTV, and resident mobile apps were installed with an experimental staff of 20 persons. As a result of the experiment, the proponents could confirm the evacuation situation in real time through the mobile app of the experimental staff. Since information on the location and number of the people who could not be evacuated can be checked in real time, it is possible to evacuate and guide evacuation efficiently through dynamic situation response. The following figure shows the contents of the cell-based location identification experiment performed in order to verify the field applicability of the required technology. The number of people in each cell was confirmed by setting the cell area of the corridor and emergency stairs where the beacon was installed. Through this experiment, it can be proven that the required technologies described in the previous section can be effectively used to derive evacuation guidance in case of fire.

cell-based location identification experiment

place	Busan Uiversity of Foreign Studies
date	November 7, 2017 18:00 ~ 19:00
# of staff	20
experiment contents	**- overview** - identify location and number of people using beacons and smartphone apps - determine the number of people in each cell by setting the cell area of the corridor and emergency stairs where the beacon is installed **- experimental results** - based on 5 seconds, it is possible to check the number and location of people by cell-based area - seventeen people clustered on the four-story stairs between 45 seconds and 1 minute from the start of the experiment - even if evacuation is completed, one person continues to stay in the 5th floor corridor **- utilization plan** - identify in real time the situation that is crowded through location identification - identify the number of people and locations that have not been evacuated - if densely populated time persists, some people may be moved to the other stair to evacuate in order to improve the evacuation efficiency

number of people evacuated by time

	5th floor corridor	5th floor stair entrance	4th floor stair	total number of people	evacuation completion
after 10 seconds	4	13	3	20	0
after 20 seconds	3	10	7	20	0
after 30 seconds	1	8	11	20	0
after 40 seconds	2	3	15	20	0
after 50 seconds	1	2	17	20	0
after 60 seconds	1	2	15	18	2
after 70 seconds	1	2	14	17	3
after 80 seconds	1	1	7	9	11
after 90 seconds	1		2	3	17
after 100 seconds	1			1	19

Fig. 9: Cell-based location identification experiment

4. Evacuation Simulation

In this paper, the short range communication technologies were utilized as beacons to identify the resident's location. The indoor spaces were divided into cells with a certain size and obtain the location information by using the signal strength, signal pattern, and signal delay received from residents' mobile devices. Then, the collected information was reflected in the evacuation route change condition formula to derive the optimal evacuation route.

4.1. Evacuation Modeling

In this paper, evacuation modeling was conducted in three stages: evacuation type derivation, horizontal evacuation path derivation, and vertical evacuation path derivation. In this study, the pathfinder, which is an evacuation simulator, was used to derive an optimal evacuation method. First, the evacuation type derivation stages proceeds as follows.

In step 1, using the simulator, calculate the evacuation completion time for all floors according to simultaneous evacuation, sequential evacuation, and evacuation of the safety floor. Assign the priority for each floor according to the type of evacuation and location of the fire. In step 2, calculate the evacuation completion time of each floor to be reflected in the evacuation route change condition formula. In step 3, calculate the evacuation time per person by dividing evacuation time from step 1 by resident number. Also, calculate the evacuation time for each floor by dividing the floor evacuation time from step 2 by the people number of each floor.

In the second stage, a horizontal evacuation route is derived through the following process. In step 1, identify the number of people in the corridor and the evacuation stairs using the location identification technology after a fire has occurred and the evacuation has started. In step 2, identify the inhabitable areas using CCTV image analysis algorithms, and calculate the average evacuation time for residents of corridors and escape stairs. In step 3, change the evacuation route by substituting the number of people and the average evacuation time per floor into the evacuation condition formula.

Finally, in the third stage, a vertical evacuation route is extracted through the following process. In step 1, apply horizontal evacuation first according to the horizontal evacuation route change condition formula. In step 2, after applying the horizontal evacuation condition, apply the vertical evacuation according to the condition of changing the vertical evacuation route.

4.2. Evacuation Type Derivation

Evacuation type derivation is a step of calculating the evacuation method for safe and rapid evacuation by using the evacuation simulator based on building information and resident information. Scenarios for the case with and without the evacuation floor in the building were constructed in order to extract the safest and shortest evacuation method. In this process, the evacuation priorities for each floor were assigned according to the type of evacuation.

In order to examine the evacuation method according to the evacuation type, the factors such as fire floor (N_f), top floor (N_h), bottom floor (N_g), and combined fire floor (M_f) were considered. First of all, simultaneous escape evacuation were conducted at all floors simultaneously ($N_g \sim N_h$).

Sequential evacuation methods were divided into two types according to how to treat the fire floor. The first method is that evacuate the fire floor first, then evacuate the other floors sequentially, and evacuation proceeds in the following order: (N_f), (N_{f+1}, N_{f+2}, N_{f+3}, N_{f-1}), ($N_{f+4} \sim N_h$), and ($N_g \sim N_{f-2}$). The second method evacuates all floors including the fire floor sequentially, and evacuation proceeds in the following order: (N_f, N_{f+1}, N_{f+2}, N_{f+3}, N_{f-1}), ($N_{f+4} \sim N_h$), and ($N_g \sim N_{f-2}$).

Even if a complex fire occurs, sequential evacuation methods were divided into two types according to how to treat the fire floor. The first method is that evacuate the fire floors first, then evacuate the other floors sequentially, and evacuation proceeds in the following order: (N_f, M_f), (N_{f+1}, N_{f+2}, N_{f+3}, N_{f-1}, M_{f+1}, M_{f+2}, M_{f+3}, M_{f-1}), ($N_{f+4} \sim N_h$, $M_{f+4} \sim M_h$), and ($N_g \sim N_{f-2}$, $M_g \sim M_{f-2}$). The second method evacuates all floors including the fire floor sequentially, and evacuation proceeds in the following order: (N_f, N_{f+1}, N_{f+2}, N_{f+3}, N_{f-1}, M_f, M_{f+1}, M_{f+2}, M_{f+3}, M_{f-1}), ($N_{f+4} \sim N_h$, $M_{f+4} \sim M_h$), and ($N_g \sim N_{f-2}$, $M_g \sim M_{f-2}$).

In the method of evacuation using the evacuation safety floor, the evacuation shelter floor should be firstly designated based on the fire floor. After designating the evacuation floors in the building, the evacuation method would be applied as follows. In the following formulas, $S=\{S_1, S_2, S_3,\} \ldots, S_k\}$ is a set of evacuation safety floors where S_1 is the highest floor.

$$N(N>(S_1-5))\rightarrow S_1 \quad \text{if } N_f > S_1 \tag{1}$$

$$N(N>S_1)\rightarrow S_1,\ N(N<S_1)\rightarrow S_2 \quad \text{if } (S_1-5) < N_f < S_1 \tag{2}$$

$$N(N>(S_1-5))\rightarrow S_1,\ N(N<(S_1-5))\rightarrow S_2 \quad \text{if } S_2<N_f<(S_1-5) \tag{3}$$

$$N(N>S_2)\rightarrow S_2,\ N(N<S_2)\rightarrow S_3 \quad \text{if } (S_2-5) < N_f < S_2 \tag{4}$$

$$N(N>(S_2-5))\rightarrow S_2,\ N(N<(S_2-5))\rightarrow S_3 \text{ if } S_2 < N_f < (S_2-5) \tag{5}$$

$$N(N > S_3)\rightarrow S_3,\ N(N < S_3)\rightarrow S_4 \text{ if } (S_3-5) < N_f < S_3 \tag{6}$$

5. Evacuation Simulation Analysis

5.1. Evacuation Simulation by Scenarios

In order to simulate evacuation, a super high-rise building should be selected first. Generally, a skyscraper is a building with a height of 300 meters or more. World famous skyscrapers include the Bourges Haripa Building, the Shanghai Tower, and the Lotte World Tower. The following figure shows an outline of a super high-rise building, the Busan International Finance Center, selected for evacuation simulation in this paper.

evacuation simulation target skyscraper overview		
region type	general commercial area	
size of land area	40,000.7㎡	
main purpose	residential facilities, commercial facilities	
structure	reinforced concrete	
total number of floors	4 floors underground ~ 63 floors above ground	
total floor area	ground floor : 352,201㎡	underground floor : 150,874.7㎡
	total	503,076.6㎡
building area	31,230.5㎡	
building-to-land ratio	78.1%	law-set building-to-land ratio : 80%
estimation area of floor area ratio	310,597.0㎡	
floor area ratio	776.5%	law-set floor area ratio : 902.57%
landscape area	12,617.9㎡	17.14%
public notice area	746.7㎡	13.37%
building height	176.7 m	

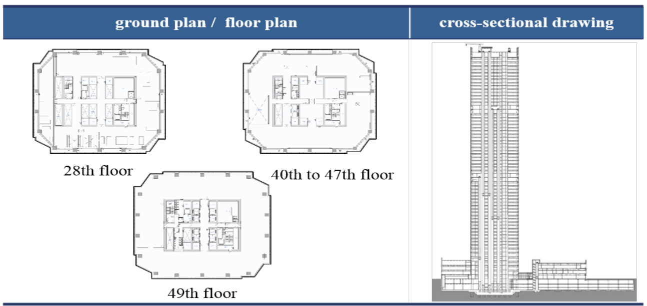


Fig. 10: Overview of evacuation simulation target skyscraper

In this paper, an evacuation simulation was performed using the Pathfinder, which is an evacuation simulator [14]. Details related to the evacuation simulation are as follows.

Table 1: Overview of evacuation simulation

	detailed description
method	simulation of whole floor evacuation, sequential evacuation, evacuation using safety floor
target	Busan International Finance Center (63rd floors) total evacuees 3,872 people
experiment	measurement of evacuation time by applying scenarios based on whole floor evacuation, sequential evacuation, and evacuation using safety floor

The following figure shows the details of the evacuation simulation using the Pathfinder. In detail, before performing the simulation, the input factors for the evacuation simulation were analyzed and the setting factors were selected. At this time, the evacuation scenario to be used for the simulation should be configured. Based on this scenario, the actual simulation was performed for each type of evacuation like as whole floor evacuation, sequential evacuation, and evacuation using the safety floor.

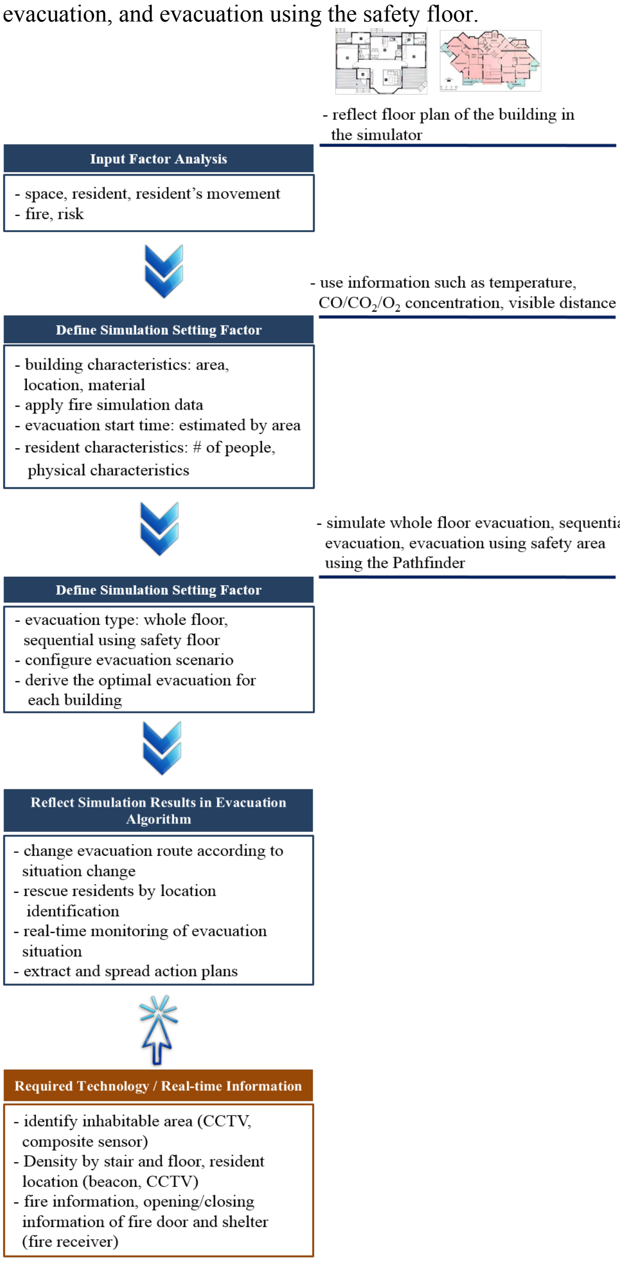


Fig. 11: Simulation sequence diagram for evacuation type derivation

As a result of the simulation, first, scenario A was for simultaneous evacuation of all floors. In detail, evacuation was carried out on 63 floors and total evacuation time was 3234.9 seconds. The following table shows the detailed results of the simulation based on scenario A.

Table 2: Simulation results of whole floor evacuation (unit: sec)

floors	1~63
# of residents	8384
minimum time	53.6
maximum time	5874.7
average time	2740.4
standard deviation	1572.0

The simulation of sequential evacuation was based on Scenario B, where the five floors including the fire floor evacuate first and the remaining floors were evacuated later. In detail, the evacuation

method of the five floors including the fire floor was classified into two ways—as sequential evacuation and simultaneous evacuation. On the other hand, the remaining floors except for the five floors evacuate at the same time.
Assuming that a fire occurred on the 32th floor in this simulation, five floors such as 31st, 32th, 33rd, 34th and 35th floor should be evacuated first. When simulation was performed using the sequential evacuation method for five floors, evacuation was carried out in order of 32th, 33th, 34th, 35th and 31th floor. The residents of the remaining floors except for the five floors were evacuated at the same time. The following table shows the results of this simulation.

Table 3: Simulation results of a sequential evacuation including sequential evacuation of 5 floors (unit: sec)

floors	5 floors	remaining floors
# of residents	760	7624
minimum time	481.6	1269.7
maximum time	1216.1	6585.1
average time	849.8	3704.2
standard deviation	206.1	1429.9

In case of simultaneous evacuation, all residents of 31th, 32th, 33th, 34th and 35th floor should evacuate at the same time in the same way as evacuation of the remaining floors. The following table shows the simulation results of sequential evacuation including simultaneous evacuation of 5 floors.

Table 4: Simulation results of sequential evacuation including simultaneous evacuation of 5 floors (unit: sec)

floors	5 floors	remaining floors
# of residents	469.9	7624
minimum time	481.6	1206.7
maximum time	1153.1	6522.1
average time	824.0	3641.2
standard deviation	193.7	1429.9

Finally, the simulation of evacuation using safety floor was performed by Scenario C. This scenario was structured to be based on the following three groups. The evacuation scenarios according to groups are as follows. Among these groups, the group 1 consists of residents of 27 floors or less, and they were evacuated to the stairs at the same time. The group 2 consists of residents from 30 to 47 floors and they were evacuated by stairs to the 29th floor designated as the safe area for evacuation. Finally, the group 3 consists of residents from 50 to 63 floors and they were evacuated by stairs to the 49th floor designated as the safe area for evacuation.
The following table shows the detailed results of the simulation based on scenario C, and total evacuation time was 1314.5 seconds. A comprehensive analysis of the simulation results shows that evacuation using safety floor was the most effective against other types of evacuation. Therefore, this method was selected as the evacuation type in this study.

Table 5: Simulation results of evacuation using safety floor(unit: sec)

	Group A	Group B	Group C
# of residents	3525	2730	2129
minimum time	53.6	123.3	161.2
maximum time	2299.1	5184.5	8464.5
average time	1177.1	2649.4	4287.0
standard deviation	639.7	1460.4	2404.1

5.2. Derivation of Horizontal Evacuation Route

In order to derive a horizontal evacuation route, firstly, the inhabitable zone information should be reflected. If an inhabitable area was found in the floor, an evacuation route using the stairs excluding the non-available area will be derived. In general, there are two emergency stairs in the east and west of a high-rise building.
In order to generate the conditional formula for changing the horizontal evacuation route, the factors such as the number of people using the west stair and the east stair (P^W, P^E), average pass time for one person on the west stair and east stair (R^W, R^E), and average passage time per person on all stairs (R^N). In the extraction of horizontal evacuation route using emergency stairs, the conditions for changing the route are defined as follows.

$$(P^W - P^E) / 2 \rightarrow W \quad \text{if } R^E < R^N < R^W \tag{7}$$

$$\text{No change (preserve existing route) if } R^E < R^W < R^N \tag{8}$$

$$(P^W - P^E) / 2 \rightarrow W \quad \text{if } R^N < R^E < R^W \tag{9}$$

$$(P^E - P^W) / 2 \rightarrow E \quad \text{if } R^W < R^N < R^E \tag{10}$$

$$\text{No change (preserve existing route) if } R^W < R^E < R^N \tag{11}$$

$$(P^E - P^W) / 2 \rightarrow E \quad \text{if } R^N < R^W < R^E \tag{12}$$

5.3. Derivation of Vertical Evacuation Route

In the derivation of the vertical evacuation route, the path change condition is defined based on density. This is because the average evacuation time in the stairs depends on the density. Therefore, this study aims to shorten the evacuation time by dispersing the evacuation density occurred when using stairs between floors having the same characteristics as the traffic jam. In a vertical evacuation, the density can be obtained by counting the number of persons through beacons installed in the stairs. When a sequential evacuation is carried out, the evacuation density is then calculated for each floor based on the evacuation of five floors, and compares the density among emergency stairs. Finally, the evacuation density should be substituted into the evacuation route change condition formula in order to extract the optimal evacuation route.
In order to generate the conditional formula for changing the vertical evacuation route, the factors such as the density of people using the west stair and the east stair (D^W, D^E) and the time that the people with evacuation routes to change have completed the move to the other side of the stair (z). In the extraction of vertical evacuation route using emergency stairs, the conditions for changing the route are defined as follows.

$$\text{No change (preserve existing route) if } D^W <= D^E + z \tag{13}$$

$$\text{Move to the other side of the stair if not } (D^W - D^E) \tag{14}$$

6. Conclusion

In the evacuation model based on location identification proposed in this study, the type of evacuation that reflects the characteristics of the building and residents should be determined. In this paper, the basic evacuation type had been selected according to the simulation results after applying the scenarios for the whole floor evacuation, sequential evacuation, and evacuation using safety floor from the evacuation simulator. When a fire occurs in high-rise buildings, evacuation starts according to the basic evacuation type. Then, an evacuation route change that can shorten the evacuation time will be extracted using the number of residents, average evacuation time, and inhabitable area which are all being collected in real time.
In comparison with a horizontal evacuation, the vertical evacuation had a lower average evacuation time due to the fact that evacuees were being guided to the most efficient route. The vertical evacuation guided the evacuees to the lower density side in order to shorten the evacuation time. Consequently, the evacuation model based on location identification will lead to a more efficient evacuation. In future research, it is necessary to derive the evacuation route and the entry route in order to avoid conflicts between firefighter's entry route and the evacuation route. To do this, the evacuation route changing conditions according to firefighter's entrance should be defined and applied.

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