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A Study on the Implement of AI-based Integrated Smart Fire Safety (ISFS) System in Public Facility

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Abstract Even at this point in the era of digital transformation, we are still facing many problems in the safety sector that cannot prevent the occurrence or spread of human casualties. When you are in an unexpected emergency, it is often difficult to respond only with human physical ability. Human casualties continue to occur at construction sites, manufacturing plants, and multi-use facilities used by many people in everyday life. If you encounter a situation where normal judgment is impossible in the event of an emergency at a life site where there are still many safety blind spots, it is difficult to cope with the existing manual guidance method. New variable guidance technology, which combines artificial intelligence and digital twin, can make it possible to prevent casualties by processing large amounts of data needed to derive appropriate countermeasures in real time beyond identifying what safety accidents occurred in unexpected crisis situations. When a simple control method that divides and monitors several CCTVs is digitally converted and combined with artificial intelligence and 3D digital twin control technology, intelligence augmentation (IA) effect can be achieved that strengthens the safety decision-making ability required in real time. With the enforcement of the Serious Disaster Enterprise Punishment Act, the importance of distributing a smart location guidance system that urgently solves the decision-making delay that occurs in safety accidents at various industrial sites and strengthens the real-time decision-making ability of field workers and managers is highlighted. The smart location guidance system that combines artificial intelligence and digital twin consists of AIoT HW equipment, wireless communication NW equipment, and intelligent SW platform. The intelligent SW platform consists of Builder that supports digital twin modeling, Watch that meets real-time control based on synchronization between real objects and digital twin models, and Simulator that supports the development and verification of various safety management scenarios using intelligent agents. The smart location guidance system provides on-site monitoring using IoT equipment, CCTV-linked intelligent image analysis, intelligent operating procedures that support workflow modeling to immediately reflect the needs of the site, situational location guidance, and digital twin virtual fencing access control technology. This paper examines the limitations of traditional fixed passive guidance methods, analyzes global technology development trends to overcome them, identifies the digital transformation properties required to switch to intelligent variable smart location guidance methods, explains the characteristics and components of AI-based public facility smart fire safety integrated system (ISFS).

Keywords Smart location guidance, AI engine, Capacity constrained routing problem, Digital Twin, Time-expanded graph network modeling, Safety digital transformation

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1. Introduction

The design of new buildings is getting bigger and more complicated by the day. As a result, construction sites are also becoming larger and more complex. Domestic complex buildings, which accommodate more than 5,000 people a day, have maintained a steep annual increase of more than 20% since 2012 when statistics began to be compiled. In the event of a disaster situation such as fire or explosion in a large-scale complex building, most conventional systems are applied to the site due to passive investment and recognition of safety facilities, despite high concerns over increased casualties. The public is anxious due to the rising social dissatisfaction caused by the international crisis surrounding Korea and the spread of infectious diseases. Large-scale complex buildings have many complex

spaces such as maze structures that are difficult to find at once, and high-density intensive facilities linked to surrounding facilities increase crowd confusion in the event of a disaster or emergency, leading to secondary damage such as movement congestion and crushing. Not only is the government aware of the seriousness of this situation and is about to implement the Punishment of Serious Disaster Companies Act, but it is also making great efforts to prevent casualties by preparing a special law on construction safety. In the era of digital transformation, it is necessary to clarify the facts of "what is the cause, who is responsible, and how to prevent a recurrence" and firmly establish it as a system. Budget execution for safety should no longer be recognized as a sunk cost, but as an essential investment to link current hope to the future.

The safety sector is no exception from the ongoing digital transformation across all industries. We should actively utilize various digital technologies to prevent casualties from unexpected disaster accidents in all spaces. Continuous efforts are required to expand the application of AI technology to the entire process leading to detection of on-site environmental changes, large-scale data analysis, real-time crisis response, and rapid follow-up improvement, and to prevent casualties. This is because it goes beyond protecting precious people's lives and is directly related to international competitiveness as an indicator of whether companies can flexibly recover from external shocks to stable operational conditions and preemptively respond to future predictable changes.

Therefore, this paper identifies the limitations and improvement directions of existing information systems, identifies desirable approaches to implement digital transformation in light of the nature of the problem, and presents expected effects of the new system.

2. Limitations of Existing Fire Safety Systems

Over the past few decades, emergency guidance systems have relied on collective evacuation methods by fixed passive guidance lights and alarm facilities (alarm, emergency broadcasting, etc.). In other words, the existing method relies on a uniform method, not various methods for responding to disaster accidents such as fire or gas leakage, and it is impossible to inform appropriate evacuation and response methods for each location of the victim, resulting in constant casualties. As shown in Figure 1, the existing guide lights serve as a guide to evacuation in the event of a fire by instructing the location and direction of the evacuation area, but they have a decisive limitation in not knowing whether the evacuation route and exit are safe in the event of an actual situation. In addition, if you rely only on safety management personnel due to the large size and complexity of buildings, blind spots will occur and the time to respond to disasters will inevitably increase structurally.

Existing fixed evacuation guidance methods are suspicious even if actual fire warnings occur due to frequent false alarms, and as a result, it is difficult for panicked people to make normal judgments, resulting in casualties or expansion. As shown in Figure 2, three main

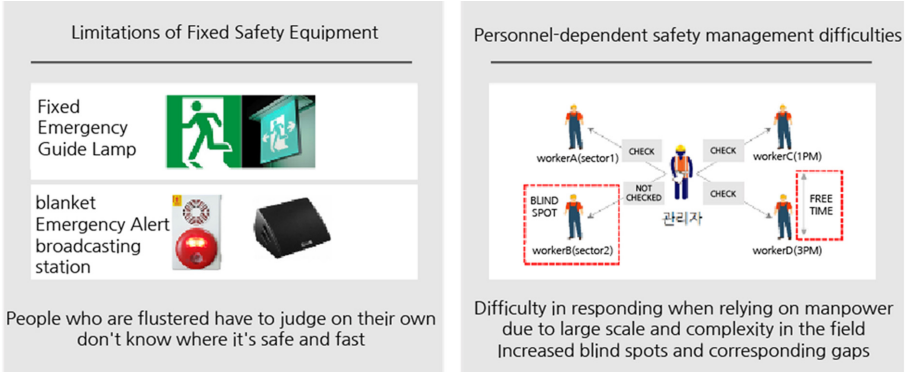


Figure 1. Limitations of fixed evacuation guidance and manpower-dependent methods.

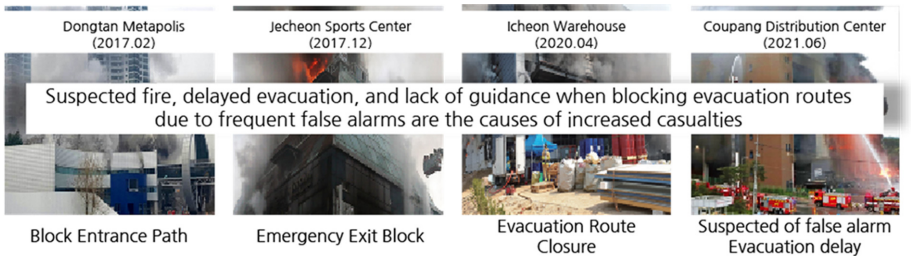


Figure 2. Causes of casualties in major fire accidents.

reasons were that the actual fire alarm was suspected of being a false alarm due to frequent false alarms, the evacuation order was delayed due to late confirmation of the fire's authenticity, and there was no real-time guidance throughout the site in an emergency.

Given that the human body may be embarrassed, blurred, and it may be difficult to immediately respond to the situation, the new safety management method should immediately detect the authenticity of alarms about fire or gas leaks, provide variable guidance according to location, and 시 respond in real time.

3. Overseas technology development trends

In Europe, the passive fixed evacuation induction method has a recognition rate of only 38% in the event of disasters and terrorism, so it is difficult to increase the evacuation rate within the golden time.1 In Europe, where major disasters have continued due to large fires and terrorism, R&D investment is being supported to urgently convert the existing passive safety management method to a new active location guidance method.

3.1. Project GETAWAY

The EU invested about 3.11 million euros for three years from November 2011 to October 2014 to carry out research and development to innovate location guidance and evacuation guidance methods in case of a disaster in underground-linked complex buildings (see Fig. 3). Tests on conventional fixed passive evacuation guidance methods in London Underground and Barcelona Metro, Spain, showed that only 38% of people were evacuated to suitable places. Existing passive evacuation guidance lights have limitations in that it is difficult to evacuate within golden time due to low recognition rates, so to overcome this, they attempted to improve the recognition rate and evacuation decision-making time for evacuation targets.[1]

However, the GETAWAY project team faced the fatal disadvantage of taking too long to calculate the evacuation route because it calculated the evacuation route using a simulation program for designing fire routes and exits in the event of a disaster. If more than 6 to 8 minutes are spent calculating routes, this is 1/3 of the average golden time in multi-use facilities, so if real-time is not secured within seconds, it is difficult to use in actual disaster situations.

3.2. eVACUATE

The eVACUATE is a large project promoted by the European Commission with an investment of more than 8.58 million euros over four years from April 2013 to May 2017 to prepare an active variable guidance system for high-rise and regional infrastructures with large populations (see Fig. 4). Efforts were made to detect large-scale personnel flows using CCTV and mobile devices, and to simultaneously provide places of danger to the general public in the event of a disaster or terrorist accident and the direction of evacuation through active guidance devices and mobile apps.2

The pilot project at Athens International Airport and

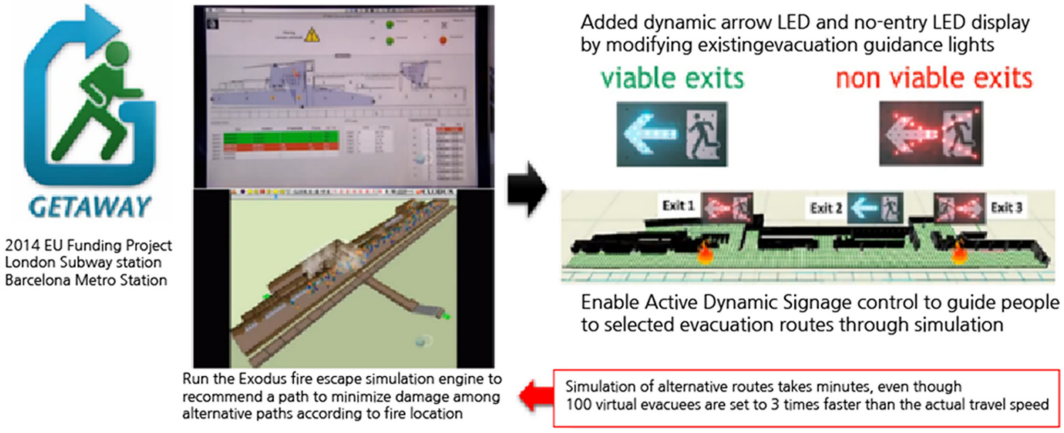


Figure 3. Project GETAWAY variable location guidance techno-logy development.



Figure 4. Development of location guidance technology for eVACUATE Project.

Real Sociedad in Spain showed an improvement effect of reducing evacuation time by 23% compared to the previous one, but it has limitations in test results in a limited space. Although eVACUATE has applied a simulation-based path selection technology with improved performance, it still has a limitation in that it takes more than tens of seconds to calculate the path, so real-time cannot be secured.

3.3. HEX Dynamic Evacuation

HEX Saving is a Taiwan-based company with excellent technology to manufacture its own fire fighting system. In conjunction with existing fire fighting systems, techniques have been developed to provide active dynamic location guidance by eliminating paths where flame or hazardous smoke is detected from available copper wires (Figure 5).

The HEX Dynamic Evacuation system provided dynamic location guidance by excluding areas where danger was detected while omitting the real-time route search process, so it showed technical limitations that only simple variable guidance was possible because fast route or entry blocking guidance was not possible.

The path from various locations inside the building to multiple exits is a three-dimensional path that combines horizontal and vertical movements, including emergency stairs. In addition, when the concept of time expansion is added to the disaster situation as it changes from time to time, the network graph model turns into a vast problem with more than hundreds of millions of possible combinations. Real-time variable guidance requires the development of a high-level algorithm that performs vast amounts of calculations in seconds to calculate safe and fast paths that are still available in an emergency in a large three-dimensional graph network. In particular, considering the growing size of the building, the size of the graph network connecting the available evacuation routes also increases rapidly, making it difficult to solve the problem due to an exponential increase in calculation time with the Dijkstra technique.

4. Integrated Smart Fire Safety (ISFS) system

4.1. Dynamic positioning problem properties

General navigation path calculation is a problem of obtaining a single path from a single starting point to a single destination. A path using a vehicle is a horizontal movement single path that exists on a plane. In contrast, the problem of calculating travel routes from various floors to multiple exits inside the building in an emergency increases complexity in three dimensions, and if the concept of time expansion is added to reflect changing disaster situations, the combination of possible travel routes rapidly expands. Figure 6 shows the com-plexity of the multi-path calculation problem of three-dimensional escape from human life in buildings with the concept of space and time expansion compared to the problem of calculating the shortest path of vehicle navigation. Although it is a simple network graph model that expresses the place where the guide device is installed and connects four nodes and nodes with a link, it is easy to see that the size of the problem increases rapidly even if the unit time increases from T0 to T4. In this type of network graph model, the problem of calculating an effective path is called the capacity constraint routing problem (CCRP), and it is well known that even if the size of the problem grows a little (i.e., even if the building grows a little), it takes a very long time to calculate the backtracking. In particular, in order to secure real-time calculation of life escape routes required in disaster situations, intelligent search techniques using AI engines different from the previous one should be applied.

The current fire law does not systematically stipulate variable guidance devices. This is a facility that must be additionally installed by the user's choice, and economic feasibility is very important. For this reason, it is difficult to use expensive large computers, including parallel computing, to complete variable path calculation in seconds, and an extremely efficient AI engine-based path search algorithm is required to calculate results in seconds only by using low-end PC server-level computers.

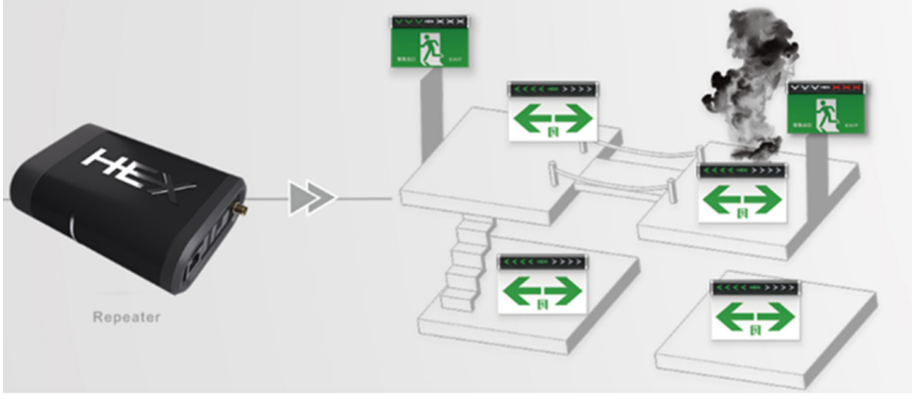


Figure 5. HEX Saving's variable location guidance system.

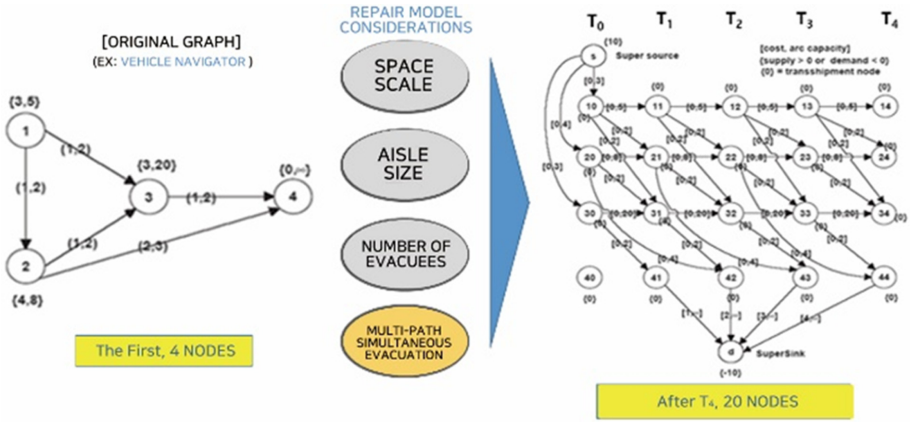


Figure 6. Complexity of Time-Extended Pathfinding Graph Model.

If location guidance devices are wired, the cost of configuring the network in the building may decrease economic feasibility, and the burden of operating hundreds of guidance devices installed in major locations in the building within seconds alone adds to the difficulty of the problem. In addition, in order to easily use the time-expanded network graph model in all buildings regardless of the type of building, a tool that automatically generates a repair model by easily connecting the location and movement of the guide device in the building to a visible three-dimensional view is required. To this end, if a three-dimensional network graph is constructed on a three-dimensional digital twin model of a building by using a major location where a guide device is installed as a node and expressing a link between nodes, it must be accompanied by the development of a technology that automatically converts it into a mathematical model that can apply an AI engine-based intelligent path calculation algorithm.

4.2. Composition of smart fire safety integrated system

In order to solve the high-level attributes of real-time variable location guidance, it went through a multi-year technology development process by converging AI engines, digital twins, and IoT technologies. The AI route search engine and the digital twin fusion Intelevac-K location guidance system are intelligent variable location guidance systems that recognize the ignition point and fire spread in the event of a fire in a building and guide safe and fast evacuation routes and travel instructions. The system was created after a long period of high-level technology development, but since it is a solution related to human life, various sites such as factories, department stores, technology development centers, culture and arts centers, and underground shopping malls were verified. The main characteristics of the system are as follows.

① Application of intelligent algorithms (ALTERA) to calculate safe and fast routes to reach multiple exits from places where guidance is installed
② Automatically convert to a time-expanded network graph model by applying digital twin 3D modeling techniques that can easily reflect evacuation lines in buildings
③ Check the real-time danger zone on the 3D control screen and perform one-click active location guidance
④ Voice, LED arrows, and high-brightness direction lights guide appropriate response instructions for each location where the information device is installed
⑤ Dynamically create and guide travel routes by

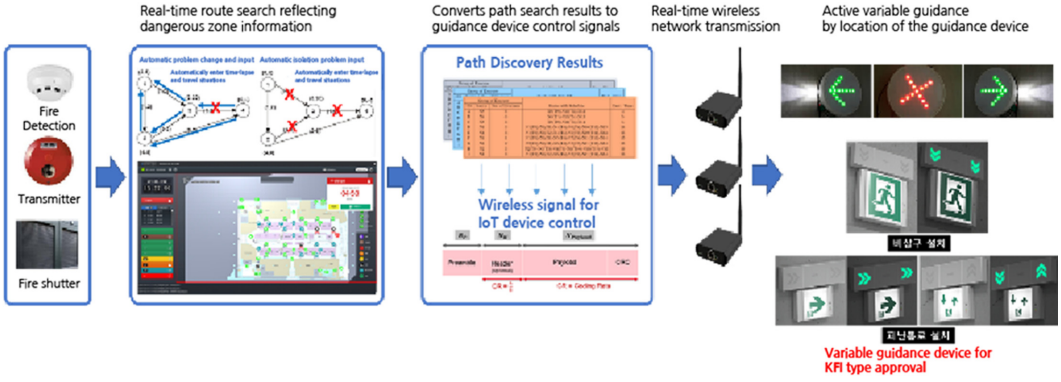


Figure 7. Composition and operation of smart fire safety integrated system.

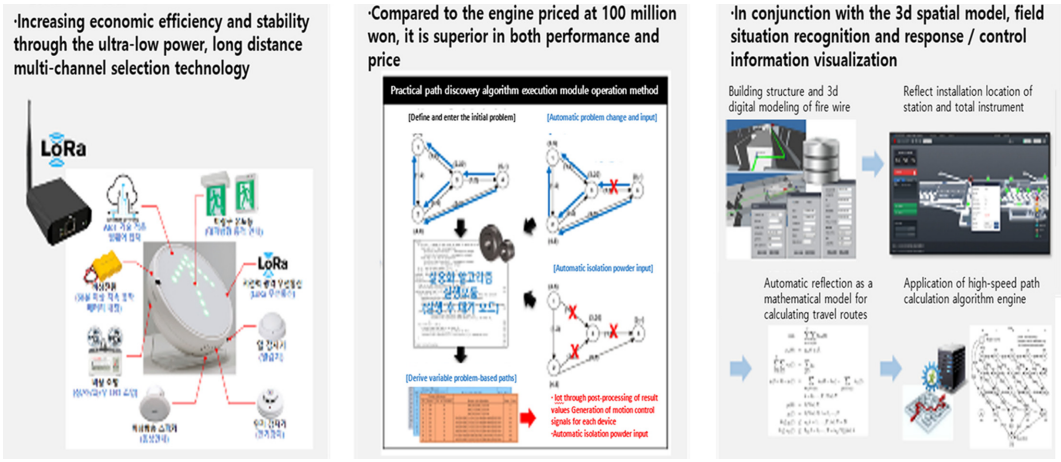


Figure 8. Core technology elements of smart fire safety integrated system.

reflecting real-time situations in which flame and hazardous smoke spread are detected

⑥ In conjunction with legal fire fighting facilities, implementation of variable dynamic location guidance to maximize survival rate in the event of a disaster

As shown in Figure 7, the smart fire safety integrated system consists of digital twin control software with intelligent algorithms that recognize dangerous situations and calculate safe routes in real time, IoT wireless repeaters that support IoT wireless communication, and smart devices that guide safe evacuation with voice, lighting, and arrows.

The core technologies included in the smart fire safety integrated system are shown in Figure 8, and it is a system that can provide effective countermeasures to prevent casualties so that the people can enjoy a safer and more convenient life.

4.3. ARTERA AI Engine

As shown in Figure 9, the Altera engine was developed to apply a safe and fast three-dimensional three-dimensional path search technique while expanding the graph according to the passage of time and the movement of the real person to reflect the changing disaster situation every second. Considering the path calculation complexity of the time-expanded network graph model, the Time-dependent Quickest Path algorithm was developed and mounted to compensate for the limitations of soaring calculation time when the model size increases.

In the case of commercial optimization calculation solvers such as IBM CPLEX, even in a simple path network model, the calculation time increases rapidly when the number of nodes increases, and the speed decreases significantly when calculating three-dimensional paths from large locations to multiple exits. In the case of the CCRP algorithm, which is a representative of the path calculation algorithm in the existing time extension graph, problems such as speed reduction and the use of fixed value travel time still occur when the size of the path network increases by relying on Dijkstra's algorithm. The Altera engine can reflect exceptions according to copper wire modeling in the network creation stage, and the shortest path is calculated by applying AI path search techniques rather than Dijkstra's algorithm in the path

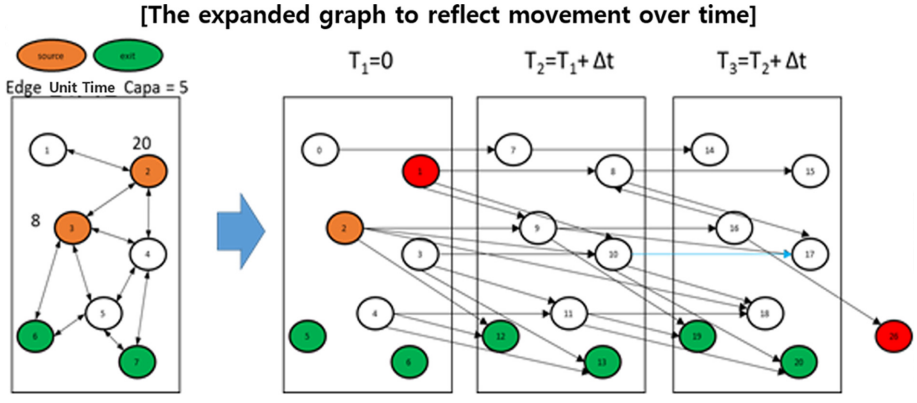


Figure 9. Path Calculation Algorithm Loaded in Altera Engine.

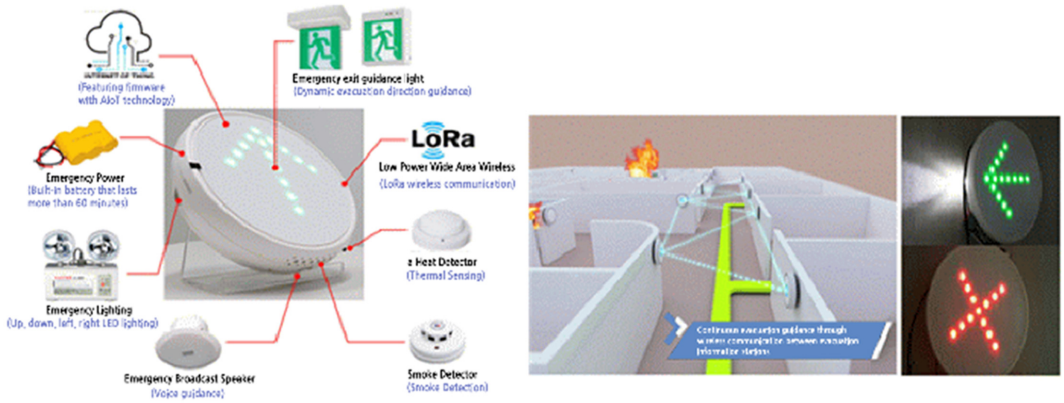


Figure 10. Intelevac-K Positioning Device.

extraction stage, so the speed is not significant even when the network grows.4 In addition, a number of real-world reflection functions were added to the actual field application process, such as exclusion of nodes that cannot be moved due to isolated nodes and disaster situations, use of two-way arcs, and limitation of stair-up arcs.5 Intel 7-5500U CPU@2.40GHz, 8.00GB, Windows 7 Ultimate K64bit) is equipped with an Altera engine, and the entire evacuation path is expressed in a node-arc graph model. The time spent searching for routes in a 10-story small and medium-sized building with 98 nodes, 252 arcs, and 1,040 evacuees is suitable for one second.

4.4. IoT technology elements

Figure shows the variable location guidance device included in the Televac-K. As shown in 10, dynamic location guidance reflecting real-time situations is provided and a triple safety device is included.

① Real-time reflection of dangerous situations on evacuation routes and variable guidance on safe and quick countermeasures
- Transfer to wireless repeater via self-contained temperature sensor and smoke sensor
- Performs evacuation direction voice guidance, LED arrows, and high luminance direction lighting guidance according to signals received from the wireless repeater
- In the absence of a fire detector, its own thermal and smoke (hydrocarbon series) sensors detect hazards

② Auto-switching to its own battery when power is cut off at all times: LoRa network repeater and ultra-low power wireless for more than 2 hours

③ In the event of loss of communication with the wireless repeater or server, bridge communication between the station's individual devices reflects changes in device status and continues to perform guidance functions As shown in Figure 11, which is used information used in anInte-K. 11, a real-time communication firmware development and KC authentication firmware development and KC authenti−cation firmware development.The two-way class C LoRa wireless communication information transmitted from the IoT smart agent station immediately transmitted from the IoT smart agent station station station.In charge of the operation control signal according to the high speed path acid discharge result, the function of transmission to a teenager smart agent station.The technical excellence of

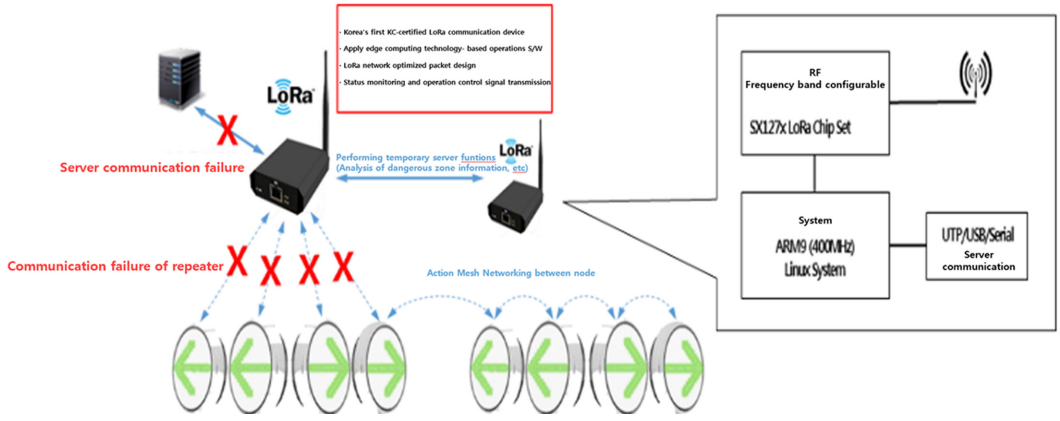


Figure 11. Intelevac-K LoRa Wireless Repeater.

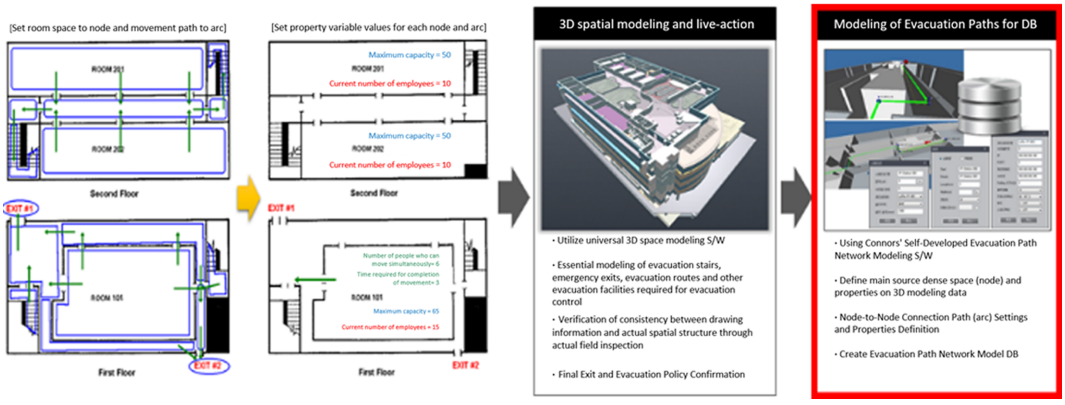


Figure 12. Automatically create a network graph model DB using Televac-K.

LoRa relay included in the Intelligence of LoRa relay is as follows.

1) (Low power, long distance) 10mW ultra-low power for longer than 2 hours with only battery to provide dozens to hundreds of times more connectivity than traditional wireless communication

2) (Economic) Hundreds to 800 meters indoors, supports over 15 kilometers in open outdoor spaces → Up to 30 smart agent stations per wireless repeater

3) (Stability) Minimize multi-channel selection wireless packet transmission errors → Ensure stable communication even in disaster situations (Use Turn spread spectrum technology to implement differentiated performance such as mesh networking between nodes, server communication disconnection, and repeater communication disconnection)

4.5. Digital twin technology elements

As shown in Figure 12, the smart fire safety integrated system reflects the evacuation line as a node and arc graph along with the internal structure on the three-dimensional spatial model of the building and automatically converts it into a path calculation repair problem based on a time-expanded network graph without complex mathematical modeling. The movement path in the building is represented by a single graph model in which nodes (location) and links (paths) are connected. It supports the application of the real-time high-speed route calculation algorithm Altera engine by reflecting easy graphic-based movements without difficult mathematical modeling. A tool was developed to place a guide device (node) in a 3D model and to generate a movement path (arc) between evacuation guide devices. This generates both node and arc connection information and attribute information as well as a simple graph modeling function.

When a 3D digital twin model is created, the smart fire safety integrated system can easily apply safety scenarios by synchronizing real-time with event data for various situations in the building, as well as performing comparative

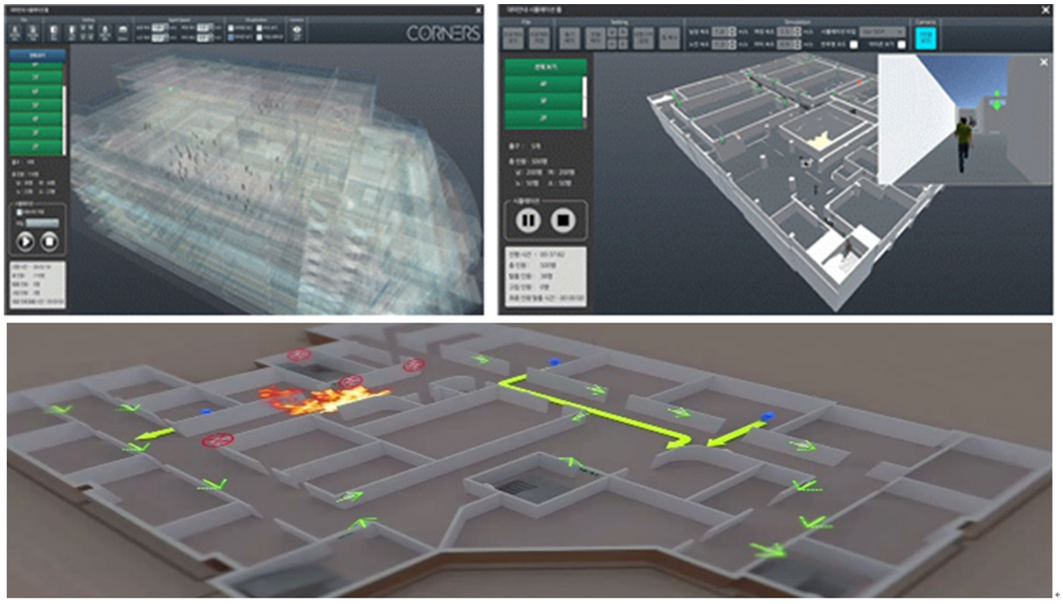


Figure 13. AI Agent-Based Simulator for Televac-K.

analysis on the expected evacuation congestion and total evacuation time. As shown in Figure 13, AI agent-based intelligent simulators are developed on their own, and dangerous situations that are difficult to execute in real buildings are generated on digital models to verify safety management scenarios and drastically shorten the time required to prepare for regular and irregular training. The main functions of the Intelevac-K simulator are as follows.

① Providing simulations reflecting the fire type, time zone, and spread according to the personnel arrangement situation by location
② Assumption of entry and detour situations according to dangerous areas ahead of the evacuation route
③ Real-time route calculation and change guidance when recognizing changes in fire conditions
④ Perform distributed evacuation guidance when predicting congestion in the early stages of an emergency
⑤ Simulation of Evacuation Route and Structural Entry Route
⑥ Calculate the total number of people, safety evacuation, isolation, rescue entry time, and total evacuation time
⑦ Comparison and Analysis of Results Before and After Application of Variable Location Guidance

4.6. Application Effect of Integrated Smart Fire Safety System

The smart fire safety integrated system studied through the high-level technology development process is equipped with an Altera AI engine, a variable guidance device using LPWA wireless communication, and a 3D digital twin control platform. The following is a summary of the key performance demonstrated by accredited test results.

① If there is a movement path between multiple stations installed in a certain space and the above stations, the movement path is defined as a graph including nodes and edges, respectively, and the evacuation guidance of objects is defined as a problem of finding the shortest path through the graph.
② In an emergency, evacuation guidance is defined as a problem of moving as many objects from the corresponding edge to a specific node (e.g., exit node) and the available people for each movement path for a unit time.
③ By defining a time-reflecting graph so that appro-priate active evacuation guidance can be carried out over time, and by creating and guiding evacuation routes reflecting the current situation over time, efficient evacuation guidance can be carried out.

It was reviewed through authorized tests that the alternative escape guidance system used instead of the lighting device to the emergency escape route in the test space implementing complex facilities, public spaces, and pedestrian corridors of public facilities met the functional and performance standards.

Table 1. Comparative measurement result of existing system and Intelevac-K

Scenario	System	Total Evacuation Time	Note
Scenario A	Existing	6 m 26s	33.1% Shorten
	Intelevac-K	4 m 18s	
Scenario B	Existing	7 m 01s	31.6% Shorten
	Intelevac-K	4 m 48s	

① Using the system, it was confirmed that the escape route can be easily identified when general emergency lighting does not perform efficient operation due to smoke.
② Using the system, it was confirmed that when one exit was not used, the way to the other exit could be easily found.
③ Using the system, it was confirmed that when moving randomly (up or down) a designated layer, it could be moved to a predetermined layer.

In particular, after placing 1,000 people inside the 8th floor of L Department Store (10 floors above ground, 1 basement floor), a multi-use facility located in Seoul, two evacuation guidance scenarios (① Scenario A: Fire broke out in the lower left and upper left stairs on the 8th floor) ② Scenario B: Evacuation guidance scenarios assuming a fire in the lower left stairwell, upper left stairwell, and lower right stairway on the 8th floor), each scenario was conducted three times, and the total evacuation completion time was measured. As a result of a performance experiment, as shown in Table 1, the evacuation reduction effect of more than 30% was confirmed when the smart location guidance system was applied compared to the existing passive evacuation guidance system.

5. Conclusios

The smart fire safety integrated system developed through this study can search for available routes in about 1 second in a 10-story small and medium-sized building that can accommodate more than 1,000 people using an Altera engine, and secured communication safety through ultra-low power long-distance wireless repeaters. In addition, it does not perform difficult mathematical modeling through 3D digital twin technology, but incorporates a real-time high-speed path calculation algorithm through easy graphic-based copper wire reflection. As a result of verifying the performance of the smart location guidance system, it was confirmed that the existing passive analog evacuation guidance system could be converted to an active digital method to actively evacuate through real-time variable location guidance reflecting risk factors. In addition, it is thought that it can be used as a system that can greatly contribute to the protection of people's lives by maximizing survival rates and minimizing casualties

by enabling active evacuation through variable evacuation guidance reflecting real-time risk situations.

Acknowledgments

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