Effect of design code and evacuation information on strategic location of Shelter in Place (SIP) in light rail station

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1. Introduction

As Korea is the only divided nation in the world, it needs to be prepared for CBRE situations (Chemical, Biological, Radiological and Explosive attacks). Currently, 341 resident evacuation facilities have been installed with the aid of government subsidies in the West Sea and border areas such as Baeknyeong, Daecheong, Socheong, and Yeonpyeong Island. 23,386 underground facilities owned by private, government, local governments, and public organizations are publicly designated and operated as evacuation facilities (National Civil Rights Commission 2014). The Ministry of Public Safety and Security’s Policy Research Report (2016.10) “A Study on the Standard Improvement of Civil Defense Resident Evacuation Facility,” mentions structural standards, required areas, and facility standards of public facilities (Korea Research Institute for National Strategy 2016). The validation of facilities affecting evacuation time during the design of the Shelter In Place (SIP) has not been studied well. Considering the situation in Korea, designing SIPs in existing private facilities to be used in cases of emergency would be better than randomly increasing the number of evacuation facilities. In normal situations the facility would be used for its general purposes.

SIP was first proposed in Israel to protect civilians. It is now a concept developed by the United States to enhance evacuation (Figure 1). It provides accessibility and has many advantages in terms of maintenance and repair. SIP is optimal for Korea, as an evacuation facility, because Korea has a high population density in its metropolitan areas.

The design paradigm is rapidly shifting to 3D object-based design from 2D design, and in response, government agencies announced roadmaps for BIM (Building Information Modeling) adoption. The Public Procurement Service announced the BIM roadmap as a short-term plan for 2010–2012, a mid-term plan for 2013–2015, and as a long-term plan after 2016. Since 2016, the PPS (Public Procurement Service) mandates BIM for all facility projects (Ministry of Health and Welfare, Korea Institute for Health and Social Affairs 2018) (Bolpagni 2013). In line with this situation, the BIM model of the light rail station, a public facility, was developed. The objectives of this study are to find the elements of the facility that should be considered for the design of SIP and then verify whether the Korean standards of these elements are satisfactory. Unlike previous studies, BIM software was used instead of 2D modeling. Through evacuation simulation, the standard of domestic facilities was verified by analyzing the location, accessibility, and user’s movement.

The public facilities designated by Seoul City as civil defense evacuation facilities can be high-rise buildings (more than two stories below the ground), subway stations, tunnels, civil defense education centers, etc (Korea Research Institute for National Strategy 2016). In this study, the underground light rail station, which has both the characteristics of a building and a civil infrastructure, was used as a sample model and modeled using Autodesk Revit software. Also, the pathfinder...
developed by Thunderhead Engineering was used for the evacuation simulation. According to Thunderhead Engineering (2015), Pathfinder meets all the criteria of the International Maritime Organization (IMO) guidelines, which are currently used as the verification criteria for evacuation programs (Thunderhead Engineering 2015).

2. Variables for evacuation simulation

2.1. Movement of occupants

2.1.1. Gait speed

Regulations regarding CBRE are mostly defined based on adults. However, the gait speed of pedestrians varies depending on the inclination they are at as well as their external factors such as height, weight, and leg length. It is also difficult to define because it is affected by gender, age, region, and culture. According to previews (Zou and Chen 2020; Gupta and Yadav 2004; Zou, Fernandes, and Chen 2021) research, the human factor (i.e., emotion and perception) for crowd evacuation simulations in emergency scenarios is emphasized. Usually, Ve (m/s), which is the speed of pedestrian in emergency scenarios is higher than V, which is the standard speed for general scenarios. As a result, walking speed varies with normal and emergency situations.

However, in this study, factors that affect gait speed in CBRE situations can be divided into three categories by excluding emotional factors and categorizing only physical factors. Impact of occupant’s personnel, physical features of the occupants and the geometry details of the structure.

First, Density or specific flow is changed according to occupant’s personnel, which affects walking speed. According to the SFPE Handbook of Fire Protection Engineering (Third Edition, 2002), crowd movement is quantitatively specified using three fundamental characteristics, all of which are expressed as rates (SFPE 2002). These are density, speed, and flow. Therefore, the gait speed is most affected by density and flow. Looking at the impact on density first (Figure 2), if the population density is less than 0.54 persons/m² (0.05 persons/ft²) of the exit route (1.85 m²/person; 20 ft²/person), individuals will move at their own pace, irrespective of the speed of others. If the population density exceeds about 3.8 persons/m² (0.35 persons/ft²), no movement will take place until a sufficient portion of the crowd has passed from the crowded area to reduce its density. Between the density limits of 0.54 and 3.8 persons/m² (0.05 and 0.35 persons/ft²) the relationship between speed and density can be considered a linear function expressed as follows:

\[ S = k - akD \]  

Where \( S \) denotes the speed along the line of travel, \( D \) denotes density in persons per unit area, \( k \) denotes constant, as shown in Table 1 (\( k = k1 \); and \( a = 2.86 \) for speed in ft/min and density in persons/ft², \( k = k2 \); and \( a = 0.266 \) for speed in m/s and density in persons/m²).

Considering, the change in gait speed according to the influence of the specific flow; specific flow, \( F_s \), is the flow of evacuating persons past a point in the exit route per unit of time per unit of effective width, \( W_e \), of the route involved. Specific flow is expressed in persons/min/ft of effective width (if the value of \( k = k1 \) from Table 1.), or persons/s/m of effective width (if the value of \( k = k2 \) from Table 1.). The equation for the specific flow is as follows. (Figure 3)

\[ F_s = SD \]  

Where \( F_s \) denotes specific flow in persons/s/m², \( D \) denotes density in persons/m², and \( S \) denotes speed of movement in m/s.

Figure 1. Global trend of SIP.
When expressing distance in feet and time in minutes, i.e. $F_s$ in persons/min/ft$^2$, density in persons/ft$^2$ and speed in ft/min combining equation $S$ and $F_s$ produces the following:

**Table 1. Gait speed.**

| Egress Component                      | $K$(ft/min) | $K$(m/s) |
|---------------------------------------|-------------|----------|
| Corridor, aisle, ramp, doorway        | 275         | 1.40     |
| Stair Riser mm (in.) Stair Tread mm (in.) |             |          |
| S1: 196 (7.5) 254 (10)                | 196         | 1.00     |
| S2: 272 (7.0) 279 (11)                | 212         | 1.08     |
| S3: 165 (6.5) 305 (12)                | 229         | 1.16     |
| S4: 165 (6.5) 330 (13)                | 242         | 1.23     |

*Figure 2. Gait speed as a function of density.*

*Figure 3. Specific flow as a function of density.*
The relationship of specific flow to density is shown in Figure 3. In each case the maximum specific flow occurs when the density is at 1.9 persons/m² (0.175 persons/ft²) of exit route space.

Other factors affecting the gait speed are physical features like the age and gender of the occupants. Fruin, et al. report that (Fruin 1987) as part of his work on pedestrian planning, he observed people on two stairs on the East Coast of the United States. On an indoor stair with a 178 mm riser and 286 mm tread, descent speeds on stairs were the following:

- Men under 30 years, 0.98 m/s
- Men between the ages of 30 to 50 years, 0.81 m/s
- Men over 50 years old, 0.67 m/s
- Women under 30 years old, 0.70 m/s
- Women between 30 to 50 years old, 0.60 m/s
- Women over 50 years old, 0.56 m/s

The maximum unhindered travel speeds to be used are those derived from data published which provides male and female walk rates as a function of age (Ando, Ota, and Oki 1988). These are distributed as shown in Figure 4 and represented by approximate piecewise functions shown in Table 2. Previous studies (Fruin 1987; Ando, Ota, and Oki 1988), confirm that gait speed is affected by the age and gender of the occupants.

Furthermore, the structure’s Geometry Information, which includes stairs tread, height, width, and door width, contribute to gait speed. Tanaboriboon and Guyano (1991) observed descent on four different stairs in Bangkok, Thailand. The first stair had a 200 mm riser and 300 mm tread, was 1,200 mm wide and speed ranged from 0.39 m/s to 0.87 m/s, with a mean speed of 0.58 m/s. The second stair was 3,000 mm wide and had a 150 mm riser and tread width of 300 mm. On the second stair, the speed ranged from 0.44 m/s to 0.82 m/s, with a mean speed of 0.60 m/s. The third stair had a 140 mm riser and 300 mm tread and was 1,200 mm wide. The minimum speed observed was 0.44 m/s and the maximum was 0.82 m/s, with a mean speed of 0.61 m/s. The final stair had a 130 mm riser, 300 mm tread, and was 1,400 mm wide. The speed ranged from 0.46 m/s to 0.89 m/s, with a mean speed of 0.6 m/s.

Lee and Lam (2006) video recorded stair use in Hong Kong mass transit railway stations during the morning peak hours (8:00 to 10:00), afternoon off-peak hours (14:00 to 16:00), and evening peak hours (17:30 to 19:30). The stair had an effective width of 1,940 mm with a riser height of 160 mm and a tread depth of 310 mm. When the stairs were at its peak capacity, the average speed of descent ranged from 0.48 m/s to 0.65 m/s. Individual speeds during stair descent varied from 0.38 m/s to 0.92 m/s and 0.29 m/s to 0.93 m/s for the unidirectional and heavy counter-flow cases, respectively.

Ye et al. (2008) video recorded stair descent from 8:00 to 10:00 a.m. in one subway station in Shanghai, China from October to November 2006. The stair had 150 mm risers, 300 mm treads, and was 3,050 mm wide. Speeds primarily fell between 0.5 m/s to 1.2 m/s for densities up to 1.7 persons/m².

![Figure 4](image-url)  
**Figure 4.** Walking speeds as a function of age and gender.

| Table 2. Regression formulation for mean travel speed values. |
|------------------------|------------------------|------------------------|
| Gender | Age(years) | Speed(m/s) |
| --- | --- | --- |
| Female | 2 ~ 8.3 | 0.06 * age + 0.5 |
| | 8.3 ~ 13.3 | 0.04 * age + 0.67 |
| | 13.3 ~ 22.25 | 0.02 * age + 0.94 |
| | 22.25 ~ 37.5 | −0.018 * age + 1.78 |
| | 37.5 ~ 70 | −0.01 * age + 1.45 |
| Male | 2 ~ 5 | 0.16 * age + 0.3 |
| | 5 ~ 12.5 | 0.06 * age + 0.8 |
| | 12.5 ~ 18.8 | 0.06 * age + 1.45 |
| | 18.8 ~ 39.2 | −0.01 * age + 1.78 |
| | 39.2 ~ 70 | −0.009 * age + 1.75 |
As discussed above, the varying factors affecting the gait speed makes it difficult to define. In addition, in this study, the horizontal speed was considered based on the gate speed according to age and gender. It is to be noted that the standards regarding the stair shape design based on the codes of each country. The vertical speed is different from the horizontal speed. Bottlenecks usually occur in the stair; i.e. the vertical speed is heavily influenced by the density of the stair-cases, unlike the horizontal speed. Therefore, in this study, it is applied according to density as defined in SFPE (Figure 2) (SFPE 2002).

Richard and Addison (2011) have reviewed “Mitsugi Bone and Joint Study”, “Hawaii Osteroporosis Study”, “Study of Osteoporotic Fractures”, “Halth Male; Based on ABS” and six other studies and summarized the average gait speed (horizontal) by gender and age in the United States, Sweden, Netherlands, Australia, Japan, Canada, Israel, Germany, France, United Kingdom, Italy, and Kuwait. The horizontal gait speed applied to the simulation profile of this study was applied as recommendation by Richard and Addison (2011). Gait speeds under 20 not shown here are listed in a research paper by Ando, Ota, and Oki (1988). Regression formulation was applied as a reference.

2.1.2. Behavior mode of pedestrian
There are two pedestrian behavior modes, Steering mode and SFPE mode. Steering mode is an algorithm where pedestrians interact with other pedestrians like human behavior and movement (Thunderhead Engineering 2015). Whereas, SFPE mode uses assumptions and numbered sets defined in SFPE (2003) (Figure 5). In SFPE mode, it is possible to control the gait speed by restricting flow or the crowd density at the door, but the pedestrians do not try to avoid each other and are transmitted through each other. That is, in the SFPE mode, even if the pedestrians are overlapped with each other, they are represented as one copper line, so that the entire line is relatively simple. In Figure 5, we can see the pedestrian movements to be different when simulated in the steering mode and SFPE mode. Therefore, in this study, the simulations are in Steering Mode for a more realistic simulation.

2.2. Number of occupants

2.2.1. Korea population trend
This study sampled a light rail station which is a public facility, the number of passengers using the facility is one of the most important variable factors in the simulation for SIP design. In 2.1.1, the gait speed was defined according to age and gender, therefore, the number of passengers using light rail was also categorized by age and gender (Table 3). According to the survey of population 2017 issued by Statics Korea (National Fire Protection Association 2012), there were 24,922,000 men and 25,021,000 women in South Korea, 98,000 more women than men, with 99.6 men per 100 women. The population of the study is classified by gender and age based on the survey of population 2017 issued by Statics Korea (Table 4).

2.2.2. Estimation of simulation personnel
The sampled station is still a structure not yet open to the public. The number of occupants in this study was based on data from the Yong-in light rail station, which has the largest number of passengers using the Korean light rail. Based on data from Seoul Metropolitan Government (2019) (Seoul Metropolitan Government 2015), the number of passengers was estimated based on the data from Myeonmok Station (40,735 people) on subway line 7, which transports the most similar

![Figure 5. Route results by simulation mode.](a) Steering Mode  (b) SFPE Mode)
number of passengers as with the Yong-in light rail station. According to Seoul Metropolitan Government (2019), 2,814 people/hour (ride) and 1,174 people/hour (get off), respectively, between 8 and 9 am, which is usually the busiest hour. In this situation the number of passengers per minute is 47 people/min, and the number of people getting off is 20 people/min. Simulations showed that, the maximum ride time for passengers from the ground to the platform was 162.5s (2.708 min), and the maximum time to get off the platform from the platform was 187.9s (3.132 min). Trains depart from Myeongmok Station every 2–3 min between 8 and 9 o’clock on weekdays to Jangam Line and every 2–3 min to Bupyeong-gu office for downline. Therefore, assuming that passengers wait up to 3 min after moving to the platform (2.708 min), the maximum time to stay in the station is 5.708 min and it takes 187.9s (3.132 min) to leave the station. So, 3.132 min, the length of time that the number of passengers on boarding and the number of passengers staying in the station at the same time is the time when the sum of the number of passengers getting on and off is the maximum.

Therefore, the number of getting on and off staying for 3.132 min was calculated and reflected in the simulation. In addition, the station was assumed to have 5 station staff members. The number of passengers in the station is thus calculated as follows:

- Number of Passengers = 47 people/min x 3.132 min = 147 people
- Number of people getting off = 20 people/min x 3.132 min = 61 people
- Estimated station staff = 5 people
- Total simulation occupants = 147 + 61 + 5 = 213 people

2.3. SIP location

The model data used in this study is light rail station, and occupants move from the ground to the first basement using escalators and stairs. The ways to move from the first basement to the second and third basement are using the elevator or emergency stairs shown Figure 6. Using the stairs on the first basement floor allows access to the fourth basement via the third basement floor, and the elevator can help go down to the 4th basement from the 1st basement directly. Since the evacuation facilities should be protected from surrounding hazards, the second and third
basements are the most appropriate. Considering the capacity of both floors, if the highlighted part of Figure 7 is designed to function as SIP, the area for the 2nd basement is 356.242 m² and that of 3rd basement is 536.285 m² (Table 5).

The following recommendations were made by FEMA453 (May 2006) recommendation (FEMA453 2006):

(a) Less Than 24 Hours: An occupancy duration of lesser than 24 hours does not require sleeping areas. The occupant load will generally be a net of 1.86 m²/person (20 square feet/person), depending upon the classification of occupancy.

(b) More Than 24 Hours: An occupancy duration greater than 24 hours requires sleeping areas. The minimum floor area, with the use of single size beds, is approximately 5.6 m²/person (60 square feet/person). With the use of bunked beds, the minimum floor area is approximately 2.8 m²/person (30 square feet/person).

For off-site industrial accidents, the occupancy duration is usually less than 24 hours; occupancy
durations longer than 24 hours are generally restricted to wartime. Therefore, in this study, we only considered less than 24 hours and simulated the location of the 3rd basement floor and the case of using both according to the scenario.

3. SIP simulation

3.1. Modeling

3.1.1. Creation of mesh
Pathfinder’s modeling is composed of rooms, stairs, doors, elevators, and ramps. The creation of a mesh is very important for constructing these elements. The places where occupants move horizontally are all designated as rooms, and there are meshes connected by many points and lines in these rooms.

3.1.2. Doors
Narrow doorways cause bottlenecks and thereby crowding, which has the greatest impact on evacuation time. The time taken by occupants to reach the SIP is an important factor to consider when designing the facility for SIP. Therefore, it is important to define the doorways geometry information according to the necessary specifications when modeling. The simulation can define doorways in terms of variables such as Min. Width, Max. Width, and Max. Depth in Pathfinder, and most importantly, creating the mesh where the doors are to be installed. If the mesh is not formed properly, it will not be accurately modeled as the width of the doorway. Pathfinder also allows you to define flow rates by specifying the number of people that can pass per second through the doorway. This function is expected to be very helpful in estimating the optimal capacity of the doorway, and to find out if the doorway needs to be improved in the future.

3.1.3. Escalator and stair
In general, stairs and escalators, like entrances, are narrow and creates bottlenecks that can often have a big impact on the overall simulation. As discussed in the section 2.1, the parameters of the steps (stair height, width and tread) have a significant effect on gait speed. The geometry information of the main stairs used in the entire model is shown in Table 6 (BD2438; Architectural Structural Standards Code 0807.6 Structure of Staircase; NIST (National Institute of Standards and Technology) 2015; International Code Council 2012; National Fire Protection Association 2012).

For safe movement on stairs, to suit both ascent and descent, Templer et al. (Templer 1992) suggests that risers be constructed between 160 mm and 183 mm (6.3 in and 7.2 in) and tread depth be at least 280 mm (11 in) wide. According to his study, a minimum tread width of 280 mm (11in) accounts for most foot and shoe sizes in this country. Additionally, risers from 117 mm to 183 mm (4.6 in to 7.2 in) had the fewest number of missteps associated with them. Table 7 shows the result of comparing the stairs raiser and treads installed in evacuation routes in Korea and abroad.

The biggest difference between an escalator and a stairway in the simulation is that the stairs remain static while the escalator moves constantly. In Pathfinder, the escalator can be modeled in the same way as the stairway, and the direction can be defined as one way. However, in this study, the escalator is modeled as a ramp and the direction is indicated as + x and -x directions. In the design standard for a subway (Facilities Part) (Main Design Criteria for Subway (Facility Field) 2018), the escalator speed is recommended to range between 0.5–0.67 m/sec, so it was conservatively defined as 0.5 m/s.

| Location                        | Riser(mm) | Tread(mm) | Width(mm) |
|--------------------------------|-----------|-----------|-----------|
| Ground level–1st basement level | 173.6     | 300       | 1600      |
| 1st–3rd basement level         | 158.2     | 280       | 5495      |
| 3rd–4th basement level         | 176.7     | 300       | 1600      |
| Emergency stairs Ground–1st basement level | 166.7     | 280       | 1000      |
| Emergency stairs 1st–2nd basement level | 176.5     | 280       | 1000      |
| Emergency Stairs               | 176.5     | 280       | 1000      |
| 2nd–3rd basement level         |           |           |           |
3.1.4. Elevator

In general, elevators in subway stations are designed to be slower than general elevators because they are generally meant for the disabled, elderly, and pregnant. In addition, the use of elevators in case of fire or disaster is limited, so this study simulates that only a few people who cannot walk by themselves use elevators. In other words, if the elderly, pregnant women, and the disabled exist among the total 213 people, the elevators located on the first basement and the fourth floor are used. The elevator speed is set at 0.75–1.0 m/s according to the elevator installation standard of the design standard for subway (Facilities Part) (Main Design Criteria for Subway (Facility Field) 2018).

3.1.5. Occupant

In this study, gait speed was applied by gender and age from 0 to 90 years, as shown in Table 4. Among the 213 people simulated, 61 and 147 people were evenly placed on the 1st and 4th floor platforms and stairs. In the case of the station staff, 3 were placed on the 1st floor and the other 2 on the 4th floor. Occupants’ age and gender were set automatically according to the proportions in Table 8, and the gait speed was defined according to gender and age.

All the scenarios were conducted with the same number of people. According to the Ministry of Health and Welfare Survey (2017) (Ministry of Health and Welfare, Korea Institute for Health and Social Affairs 2018), the number of persons with disabilities in 2017 was 2.67 million, 13.8% of the total population was identified as disabled, and 19.5% of people with disabilities had some help in daily life; 8.9% mostly needed help, and 5.5% needed little help in their daily lives. This means that 33.9% of the total disabled population needs help in their daily life. Considering the ratio of disabled people in Korea (13.8%) based on 208 people excluding the crew of the 213 total simulation personnel, 29 are calculated as disabled. Among the disabled, 33.9% of 29 people need help in daily life, so in this study, 10 people were considered as the number of disabled people who need help. In addition, the staff and the nearest occupants around them were simulated to help the disabled people move to SIP (Figure 8).

3.2. Scenario

As showed Table 9, it is assumed that occupants need to be accommodated for less than 24 hours where facilities to sleep are not required in the CBRE situation. Evacuations of the 3rd floor and that of the 2nd and 3rd floors were considered in the Scenario A and B, respectively. Designating the 3rd floor as the SIP showed that, accessibility was bad and the distance to SIP was too long, resulting in a long evacuation time. Therefore, this study suggested and reviewed Scenario C and D to improve this condition.

3.2.1. Scenario A

Scenario A designated the 3rd basement as a SIP and set all occupants to move to the 3rd basement. The simulation results showed that the minimum time needed by occupants to reach the 3rd basement was 47.4s, the maximum time was 396.6s, and the average time was 218.7s. The distance traveled by occupants was at a minimum of 14.0 m, maximum of 189.3 m, and an average 105.9 m. In addition, room 95 and 135, which had to pass after 20s to go to the emergency

| Table 7. Riser and tread dimension. |
|------------------------------------|
| Raiser | Tread | Remark |
|--------|-------|--------|
| Korea  | Under 200 mm | Over 240 mm |
| IBC & LSC | 102 mm ~ 178 mm | Over 279 mm |
| NIST  | 150 mm ~ 198 mm | 241 mm ~ 305 mm |
| BRE Report | 130 ~ 180 mm | 300 mm ~ 450 mm |

\*IBC: International Building Code, LSC: NFPA’s Life Safety Code, NIST: National Institute of Standards and Technology, BRE: Building Research Establishment

| Table 8. Population percentage and walking speed by age. |
|------------------------------------------------------|
| Age | Percentage (%) | Walking speed (m/s) | Percentage (%) | Walking speed (m/s) |
|-----|----------------|---------------------|----------------|---------------------|
| 0 ~ 9 | 4.496 | 0.670 | 4.533 | 0.515 |
| 10 ~ 19 | 5.600 | 1.501 | 5.645 | 1.195 |
| 20 ~ 29 | 6.426 | 1.358 | 6.478 | 1.341 |
| 30 ~ 39 | 7.409 | 1.433 | 7.469 | 1.337 |
| 40 ~ 49 | 8.499 | 1.434 | 8.567 | 1.390 |
| 50 ~ 59 | 8.024 | 1.433 | 8.089 | 1.313 |
| 60 ~ 69 | 4.886 | 1.339 | 4.926 | 1.241 |
| 70 ~ 79 | 3.123 | 1.262 | 3.148 | 1.132 |
| 80 ~ 99 | 1.337 | 0.968 | 1.337 | 0.943 |
| Total | 49.800 | | 50.201 | |
stairs, were found to have bottlenecks due to overlapping occupants in a narrow area (Figure 9). As shown in Figure 10, it can be confirmed that the bottleneck is severe enough for Room135 to use up to 10 people in a small area of 4.626 m² in simulation time of 146 sec ~ 162 sec. It is believed that there may be a risk of another accident when evacuating.

3.2.2. Scenario B
Scenario B is almost the same as in Scenario A, but the location of the SIP was modified to the 2nd basement and 3rd basement. Since the 2nd basement was at relatively shorter evacuation distance, the most acceptable capacity was estimated to be 192 people, and the remaining 21 people to be accommodated on the 3rd Basement. As a result, the minimum time taken for occupants to move to the 3rd basement was 46.6 s, the maximum time was 291.9s, and the average time was 127.3s (Figure 11). The minimum travel distance was 14.4 m, the maximum travel distance was 170.1 m, and the average travel distance was 76.4 m. Compared to Scenario A, the total evacuation time was reduced by approximately 98.6s from 396.6s to 298.0s, reducing the evacuation time by approximately 24.86%. In Scenarios A and B, congestion occurred in Room 95 in the first basement, but in Scenario C, the bottleneck caused by the concentration of pedestrians in Room135 (Figure 12), which is narrow room, was resolved relatively quickly.

3.2.3. Scenario C
In Scenario C, after setting up a staircase connecting the 4th basement and 3rd basement, 121 occupants in the 1st basement were moved to the 2nd basement and 92 occupants in the platform on the 4th basement were moved to the 3rd basement. Simulation results showed that the minimum time for pedestrians to move to the SIP was 21.8s, the maximum time was 291.9s, and the average time was 127.3s (Figure 11). The minimum travel distance was 14.4 m, the maximum travel distance was 170.1 m, and the average travel distance was 76.4 m.

The table below shows the location of the SIP and the occupants' personnel for each scenario:

| Scenario | Location of SIP and Occupant’s Personnel |
|----------|-----------------------------------------|
| A        | 2nd Basement | 3rd Basement | Description |
|          | 213          | 21           | Only the 3rd basement floor is used as SIP |
| B        | 192          | 21           | Both the 3rd and 4th floors are used as SIP |
| C        | 121          | 92           | Add one side of stairs between the 3rd and 4th basement floor |
| D        | 121          | 92           | Add both sides of stairs between the 3rd and 4th basement floor |

Figure 8. Simulation model with occupants.

Table 9. Location of SIP and Occupant’s Personnel.

![Simulation model with occupants.](image-url)
3.2.4. Scenario D
Scenario D has the same conditions as in Scenario C, except that both sides of the stairs were installed from the 4th basement to the 3rd floor, unlike Scenario C where only one side of the stairs were installed. As a result, the minimum time required for pedestrians to travel to SIP was 21.8s, the maximum time was 281.5s, and the average time was 120.2s. The minimum distance was 14.3 m, the maximum distance was 173.9 m, and the average distance was 72.0 m.

The results of each scenario are summarized in Table 10. When designing SIPs, two important factors to be considered are evacuation distances and evacuation routes. In Scenario B, the evacuation distance was reduced by 11.2 m (5.92%), from 189.3 m to 178.1 m by dividing the location of SIP into 2nd and 3rd basements.
Figure 11. Scenario C (Add Stair).

Figure 12. Scenario C room 135 usage.

Table 10. Result by Scenario.

| Scenario | A     | B     | C     | D     | Remark |
|----------|-------|-------|-------|-------|--------|
| Min. Time (sec) | 47.4  | 46.6  | 21.8  | 21.8  |        |
| Max. Time (sec)  | 396.6 | 390.0 | 298.0 | 281.5 |        |
| Average Time (sec) | 218.7 | 187.5 | 127.3 | 120.2 |        |
| Min. distance (m) | 14.0  | 15.2  | 14.4  | 14.3  |        |
| Max. distance (m)  | 189.3 | 178.1 | 170.1 | 173.9 |        |
| Average distance (m) | 105.9 | 90.6  | 76.4  | 72.0  |        |
7.5s (1.66%) was reduced. Scenarios C and D improved the evacuation route by installing additional emergency stairs, reducing the evacuation distance by up to 15.4 m (8.14%), and reducing the evacuation time by 115.1s (29.02%) from 396.6s to 281.5s.

3.3. Review Korea design code

As shown in Table 6, the stair riser and tread presented in Korea’s Building Structural Code (2009) (International Code Council 2012) stair structure are somewhat different from those of overseas standards such as BRE (Building Research Establishment) (BD2438), NIST (National Institute of Standards and Technology) (NIST (National Institute of Standards and Technology) 2015), IBC (International Building Code) (International Code Council 2012), and LSC (NFPA’s Life Safety Code) (National Fire Protection Association 2012). Stair riser is usually 200 mm in Korea, up to 178 mm in IBC & LSC and 180 mm in BRE (BD2438). According to Templer (1992), the value of riser between 117 mm and 183 mm can reduce most missteps. BRE research shows that the lower stair riser and the higher tread make a more positive impact for occupants’ evacuation, but more missteps occur at a stair tread over 350 mm (BD2438). Therefore, this study conducts how the change of stair risers and tread affects evacuation time based on Scenario A. The stairs riser is reduced to 180 mm considering the maximum misstep suggested by Templer (1992) and limited to the BRE, IBC & LSC. Cases A and B change stair riser. Cases C, D and E changes tread, and Case F changes stair width. Table 11 shows the variable values for each case.

3.3.1. Case A

In Case A, all the existing stair risers 158.2–176.5 mm were changed to 180 mm. The minimum evacuation time required for occupants to move to SIP was 45.8s, maximum time was 403.5s, and average time was 222.7s. The minimum evacuation distance was 14.4 m, the maximum evacuation distance was 193.8 m, and the average evacuation distance was 107.3 m. Compared with the previous Scenario A, the evacuation time to SIP increased by 6.9s (1.74%) from 396.6s to 403.5s and the evacuation distance increased by 4.5 m (2.38%) from 189.3 m to 193.8 m. Although the riser of the staircase is less than 200 mm according to the Korea Building code, the current staircase of the railway station is 166.7–176.5 m and the stair riser is installed lower than 180 mm. Therefore, evacuation time and evacuation distance are both increased.

3.3.2. Case B

In Case B, the stair riser was 20 mm higher than Case A, and the minimum evacuation time was 45.5s, the maximum was 406.7s, and the average was 224.9s. The minimum evacuation distance was 14.1 m, the maximum was 201.1 m, and the average was 107.0 m. The maximum evacuation distance increased by 11.8 m (6.23%) compared to the existing evacuation distance of 189.3 m, and 7.3 m (3.77%) compared with that of Case A,193.8 m. Evacuation time increased by 101.1s (2.55%), from 396.6s to 406.7s, and 3.20s (0.79%) compared with Case A. As a result, when the riser was high, it was confirmed that adverse results were obtained for evacuation time and travel distance.

3.3.3. Case C

In Case C, the existing stair treads are 280–300 mm, and after changing them all to 300 mm and checking the results, the minimum evacuation time to evacuate to SIP was 50.2s, maximum was 393.6s, average was 217.5s. The minimum evacuation distance was 13.8 m, up to 194.2 m, with an average of 106.8 m. This increased the travel distance by 4.9 m (2.59%) compared to Scenario A, but reduced evacuation time to SIP by 3.0 seconds (0.76%).

3.3.4. Case D

In Case D, the stair treads were all changed to 350 mm, resulting in the minimum time required for occupants to evacuate to SIP was 49.3s, the maximum was 374.6s, and the average was 208.5s, minimum evacuation distance was 13.8 m, maximum was 201.0 m, the average was 106.7 m. This increased the evacuation distance by 11.7 m (6.18%) compared to Scenario A and reduced the time required to SIP by 22s (5.55%).

Table 11. Location of SIP and Occupant’s Personnel.

| Scenario | Riser (mm) | Tread (mm) | Stair Width (mm) | Remark |
|----------|------------|------------|------------------|--------|
| Origin   | 158.2 – 176.5 | 280 – 300 | 1000             | -      |
| A        | 180        | 280 – 300  | 1000             | Change Riser to 180 |
| B        | 200        | 280 – 300  | 1000             | Change Riser to 200 |
| C        | 158.2 – 176.5 | 300     | 1000             | Change Tread to 300 |
| D        | 158.2 – 176.5 | 350     | 1000             | Change Tread to 350 |
| E        | 158.2 – 176.5 | 400     | 1000             | Change Tread to 400 |
| F        | 158.2 – 176.5 | 280 – 300 | 1200             | Change Stair Width to 1200 |
3.3.5. Case E
In Case E, after changing all stair treads to 400 mm and checking the results, the minimum evacuation time required for occupants to evacuate to SIP was 47.3s, the maximum was 372.8s, and the average was 206.4s and minimum evacuation distance was 14.4 m, maximum was 192.7 m, and the average was 106.9 m.

3.3.6. Case F
In Case F, the existing stair width does not meet the Korea Building code. As a result of simulation with stair width adjusted to 1,200 mm, the minimum evacuation time was observed to be 47.9s, maximum time was 361.6s, and average was 202.6s, and minimum evacuation distance to SIP was 14.2 m, maximum was 195.3 m, and average was 103.8 m. The increased evacuation distance was 6 m (3.17%) but the time was reduced by 35s (8.83%) from 396.6s to 361.6s.

4. Conclusions

4.1. Result of scenarios
The current model was designed without considering SIP, but the simulation results confirmed that the evacuation time is reduced when considering the evacuation distance to SIP and the evacuation route (Table 12). When the SIP design is considered, the reinforcement of the SIP structure will be necessary, but before that, there is a need to select the position of the SIP and to improve the movement of the entire light rail station. If the location of SIP is accommodated separately from the 3rd basement and 2nd basement as in Scenario B, the evacuation time is reduced by up to 6.6s and the distance is 11.2 m shorter than Scenario A which accommodates the 3rd basement only. As the current light rail station has a long evacuation distance, in order to compensate for this, additional emergency stairs that can be moved directly from the 4th basement to the 3rd basement like Scenarios C and D need to be installed. As a result, the evacuation time can be reduced by up to 115.1s compared to Scenario A, which improved the evacuation time by 29.02%. Even if the construction was complete, and the location of the SIP was distributed to several places, the time saved was only 6.6s. However, when constructing the location and route of SIP in the design stage, it can be shortened to 115.1s. In this study, it was confirmed that it is much more efficient to consider evacuation distance and time to SIP in the design stage.

4.2. Result of Korea code review
The current light rail station was designed without consideration of SIP for the occupant traffic. The present design does not fit the requirements for SIP. The most influential factors in the SIP evacuation time is the geometry information such as the stair raiser, tread, and width. As shown in Table 6, Korea’s code for stair geometries, such as raiser and tread dimension, was found to be somewhat different from international codes such as IBC, LSC, BRE (BD2438), (International Code Council 2012), (National Fire Protection Association 2012).

The impact of changing the current model to follow international standards of evacuation time and evacuation distance was studied, and the results were:

(1) The stair riser limited to less than 200 mm in Korea code, it is limited to 102–178 mm for IBC & LSC, 150–198 mm for NIST and 130–180 mm for BRE. The current model is designed from 158.2 mm to 176.5 mm, as shown in Table 7. In Scenario A analyzed without stair riser change, evacuation time was 396.6s. In Case A, all raisers were slightly increased to 180 mm, which resulted in an increase in maximum evacuation time, by 6.9s to 403.5s. In Case B, changing the stair raiser to 200 mm increased the maximum evacuation time to 406.7s, an increase of 10.1s in evacuation time compared to Scenario A. In conclusion, it was confirmed that the lower the raisers had a positive effect on evacuation time. Templer et al. suggested that the riser height to be was 160–180 mm because 117–

Table 12. Result of Scenario A to D and Case A to F.

| Occupants (Persons) | Time | Distance |
|---------------------|------|----------|
|                     | B2   | B3       | Max time | Rate | Variation | Max Distance | Rate | Variation |
| Scenario A          | -    | 213      | 396.6    | -    | -         | 189.3        |      |           |
| Scenario B          | 192  | 21       | 390.0    | 98.34%| -6.600    | 178.1        | 94.08%| -11.200   |
| Scenario C          | 121  | 92       | 298.0    | 75.14%| -98.600   | 170.1        | 89.86%| -19.200   |
| Scenario D          | 121  | 92       | 281.5    | 70.98%| -115.100  | 163.9        | 91.86%| -15.400   |
| Case A              | -    | 213      | 403.5    | 101.74%| 6.900     | 193.8        | 102.38%| 4.500     |
| Case B              | -    | 213      | 406.7    | 102.55%| 10.100    | 201.1        | 106.23%| 11.800    |
| Case C              | -    | 213      | 393.6    | 99.24%| -3.000    | 194.2        | 102.59%| 4.900     |
| Case D              | -    | 213      | 374.6    | 94.45%| -22.000   | 201          | 106.18%| 11.700    |
| Case E              | -    | 213      | 372.8    | 94.00%| -23.800   | 192.7        | 101.80%| 3.400     |
| Case F              | -    | 213      | 361.6    | 91.17%| -35.000   | 195.3        | 103.17%| 6.000     |
183 mm was observed to produce the least number of missteps. The simulation results suggest, the maximum raiser value to be 180 mm.

(2) Stair tread is suggested to be more than 240 mm according to Korea code, more than 279 mm in IBC & LSC, 241–305 mm according to NIST, and 300–450 mm in BRE. The current model is designed to 280–300 mm. In Case C, the stair treads were all modified to 300 mm and the simulation time was 393.6s, which was 3s less than the simulated Scenario A. In Case D, changing the tread to 350 mm changed the evacuation time to 374.6s which was 22s less than Scenario A. In Case E, evacuation time was reduced by up to 23.8s when the tread was increased to 400 mm. Therefore, it was confirmed that increase in stair tread had a positive effect on evacuation time. The 240 mm stair tread defined in Korea Building Code was found to be very small compared to other codes abroad and had a negative effect on evacuation time. Therefore, according to the research results, it is suggested to modify the stair tread to at least 300 mm.

(3) In Case F, the width of the emergency staircase was designed to be 1000 mm, but according to the Architectural Structural Standards Code 0807.6 Structure of Staircase, the width of the indoor evacuation staircase was defined to be more than 1,200 mm. As mentioned earlier, the geometry information of the stairs was closely related to the evacuation time, so it was found to be 361.6s which was 35s shorter than the Scenario A as a result of simulation by changing it to 1,200 mm according to the Building Structural Code.

Acknowledgments

This research was supported by a grant (19CTAP-C151911 -01) from Technology Advancement Research Program(TARP) funded by Ministry of Land, Infrastructure and Transport of Korean government.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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