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Evaluation of Evacuation Safety of High School According to Change in the Width of Hallway

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Abstract

The purpose of this study is to measure the change in evacuation time at high schools according to the change in hallway width using an evacuation simulation program and to analyze the result of such change. In order to measure the evacuation time according to the change in the hallway width according to the 「Rules on the Standards for Evacuation and Fire Protection Structures of Buildings」 and to analyze the change in evacuation time resulted from the increase in the number of occupants, a scenario was constructed by applying the 「performance-oriented design method and standard for firefighting facilities, etc.」. As a result of the experiment, it was found that the evacuation time was the shortest when the width of the hallway was the widest, which was 3m. On the other hand, the evacuation time took the longest at 1.8m, which was the width of the second narrowest hallway. For the safety of high school students who spend a lot of time at school, it is necessary to secure a wide hallway width when building a new school or to provide periodic safety education in the case of an existing school whose hallways are considered narrow.

Keywords: *High-School, Hallway Width, Evacuation time, Evacuation simulation, Pathfinder*

1. Introduction

In the revised curriculum of 2015, emphasis is placed on the linked operation of elementary, middle and hig h school level curriculum and safety education. [1] School is a space where minor students in their growth pe riod can freely engage in activities, and they face various accidents because it is a place of learning in which various educational activities such as experiments and practices, field trips, and physical education activities are developed simultaneously and complexly. [2] In the space where students reside every day, elements that threaten safety are latent in everyday life. In particular, adolescents are more likely to have safety accidents than adults due to a relatively lack of awareness of risks. [3] As such, for Korea'

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s domestic cases, the ratio of teachers to students is high and it is not realistic to secure safety personnel within the school premises. In addition, it appears that students are always exposed to risks due to lack of guidance and safety awareness of students according to systematic safety rules. [4] From that point of view, schools, where teenagers spend a lot of time, are also places with the highest risk of accidents.

There are many types of accidents that occur in schools. However, since there are many accidents caused by individual carelessness, continuous safety education in schools and accident prevention education through safety programs are especially important. [5] According to the structure of the school building, the current school space is composed of classrooms and corridors. It consists of a typical straight structure with toilets and stairs arranged, and it is difficult to evacuate in case of fire due to aging of the structure and the structural issues of such buildings. In addition, when designing most school buildings, considerations of general evacuation apply only to construction-related laws, so designs for rapid evacuation have not been reviewed. Therefore, many casualties are concerned in case of fire. [6], [7] For that reason, it is necessary to predict the necessary evacuation time and determine safety by considering the space of the school using an evacuation simulation program. [8]

The purpose of this study is to analyze safety evaluation for high school evacuation according to the change of the width of hallways to secure evacuation safety in school by using a simulation program. The purpose is to minimize human casualties in the event of a fire by analyzing REST (Required Safe Egress Time, time required for evacuation) according to changes in corridor width for high school buildings with 1 basement floor and 5 floors above ground.

In a study by Soon-Beom Lee, Jae-Young Lee, and Ha-Sung Kong (2021), class arrangement plans for each floor were analyzed for securing evacuation safety in a 5-story high school building. When arranging students in school buildings with multiple floors, it was suggested that arranging them from the lower floors is effective in terms of evacuation safety. In the study of Yang Hyeong-mo and Lee Jae-rim (2016), it is intended to reflect the research on the direction of facility improvement to prevent safety accidents in school life. Through this, the study intends to design a layout for evacuation safety education centered on continuous and repetitive experiences that can minimize safety accidents due to changes in corridor width. Unlike the study on human characteristics that determine evacuation time by Jeongsoo Lee et al. (2011), this study focused on safety evaluation according to changes in corridor width that can reduce delay in evacuation time in a school building with both stairs and ramps. In the evaluation of evacuation safety through evacuation drills and simulations in high school buildings by Jeong Moo-heon et al. (2008), 8% of students failed to evacuate, and Simulex showed that 40% failed to evacuate in the actual evacuation drills. In this way, in order to reduce human casualties in case of fire, the desirable installation standards for the width of stairs and corridors, which are environmental factors, can increase the fire safety of buildings.

According to previous studies, many studies on high school floor layout and safety accidents have been conducted, but studies on high school evacuation safety evaluation according to changes in corridor width are extraordinarily little and imperfect. Therefore, it is an especially important part of helping high school students for them to evacuate to a safe place to find out what kind of correlation there is from the change in corridor width and the casualties so that it can help students evacuate safely and effectively. This is because the most important response plan in the event of a fire is the continuous evacuation drills and education in everyday life. In particular, considering the school situation where the number of teachers is insufficient compared to the number of students, it is judged that the evacuation safety evaluation through evacuation simulation will be immensely helpful in preventing safety accidents of students.

There are standards for the width and installation of corridors in Article 15-2 of the 「Regulations on Standards for Evacuation and Fire Protection Structures of Buildings」. According to Article 48 of the relevant rule, the effective width of corridors installed in kindergarten, elementary, middle, and high school buildings is regulated from 1.8m to 2.4m. In this study, simulations were conducted for evacuation situations in the event of a disaster when the change in high school corridor width was 1.5m, 1.8m, 2.4m, and 3m. This study aims to measure the evacuation time according to the change in corridor width of a high school building with one basement floor and five floors above ground, and compare and analyze the corresponding changes in evacuation time.

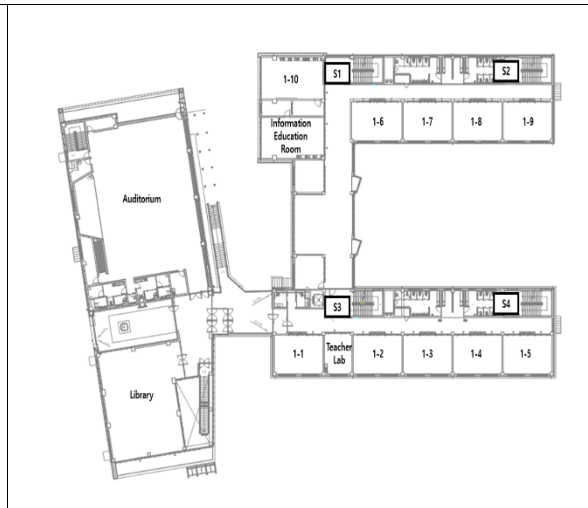
2. Evacuation simulation

Evacuation simulation predicts the time required for people to evacuate according to the width of the corridor in the building in case of fire. Based on this, it is possible to evaluate how much delays in evacuation activities can be reduced by improving specific facilities or improving evacuation procedures. Through the results of the evaluation, students can be helped to derive optimal evacuation facilities and evacuation procedures. [9] In this study, the Pathfinder simulation program was used.

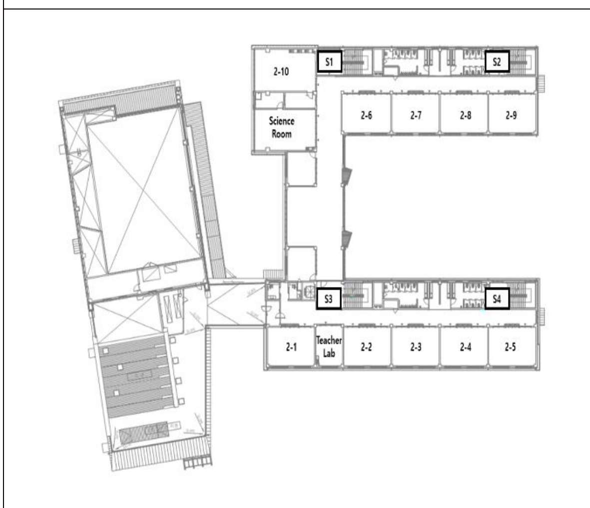
2.1 Structure of Buildings

The target building is a hallway with living rooms on both sides located in Jeonju, Jeollabuk-do. It is a 00 high school building with a total floor area of 11,387.61m² and a building area of 3,838.96m², with one basement level and five floors above ground. The first basement floor is used as a machine room and an electricity room, and the fifth floor on the ground is not a place where students reside, and those rooms for a music room, art room, and home base room were excluded from the study. The first floor contains administrative offices, principal's office, audio-video room, teachers' office, social room, and health room. On the second floor, there are 10 classrooms for all 1st graders, a teacher's research room, an information education room, and a library. The 3rd floor has 10 classrooms for all 2nd graders, a teacher's research room, a multipurpose room, and a preparation room. The 4th floor consists of 10 classrooms for all 3rd graders, a teacher's research room, a preparation room, and an art room. The floor plan from the 1st floor to the 4th floor, set as the subject of study, is shown in Fig. 1. and the floor plans of the first basement floor and the fifth floor, which were excluded from the study, were excluded.

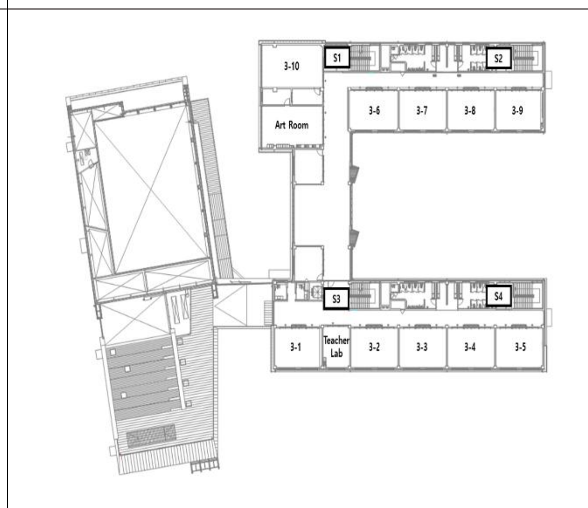
(a) 1st Floor Plan



(b) 2nd Floor Plan



(c) 3rd Floor Plan



(d) 4th Floor Plan

Figure 1. Floor Plan

As shown in Table 1, the width of the corridor on each floor is 3m, which satisfies the width and installation standards of Article 15-2 of the 「Rules on Standards for Evacuation and Fire Protection Structures of Buildings」 specified in the Building Act.

Table 1. Corridor width and installation standards

Category	Corridor with living rooms on both sides	Other corridor	Target building	Judgment
High school	2.4m or more	1.8m or more	3m	Appropriate

2.2 Calculation of capacity and arrangement of occupants

2.2.1 Based on actual number of people

In the case of teaching staff, there were 68 teachers and 30 general education administrators, and a total of 98 people are working in the building. In the case of faculty members, they were arranged in the same way as the current school arrangement. Table 2 shows the staff placement results.

Table 2. Faculty Placement Status

Cate-gory	Teacher					General education administrator				
	Principal	Vice Principal	Senior Teacher	Junior Teacher	Teacher	Administrative Office Manager	General administrative position	Hands-on worker	Cooking Staff	Others
Male	1	1		6	23		5	1		2
Female			1	7	29	1	3	5	10	3
Occupied Floor	1 F	1 F	1 F	1 F :4 2 F:3 3 F :3 4 F :3	1 F : 7 2 F : 15 3 F : 15 4 F : 15	1 F	1 F	1 F	1 F	1 F

Classroom floor area is 64.8m² for classes 1 to 9 in each grade, and 82.13m² for class 10. In the case of a class with the smallest number of students of 20 (3.24m²/1 person),

Classroom floor area is 64.8m² for classes 1 to 9 in each grade, and 82.13m² for class 10. In the case of a class with the smallest number of students of 20 (3.24m²/1 person), the standard for calculating the capacity is satisfied when the majority of classrooms are 64.8m². In the case of a class with 35 students (2.35m²/1 student), which has the largest number of students, the standard for calculating the capacity was not satisfied when the size of the majority of classrooms was 64.8m². However, in the case of class 10, which has a large class size, the standard for calculating the capacity was satisfied.

Table 3. Based on actual number of students

Usage	Criteria for calculating capacity	Actual number of people	Capacity calculation and placement		
			Total number of people	Grade	Persons
Classroom	1.9m²/person	Max 35 (2.35m²/1 person)	815 people	1st grade (2nd floor)	279

		Min 20 (3.24m²/1 person)		2nd year (3rd floor)	260
				3rd grade (4th floor)	276

In the case of students, 1st graders were placed on the 2nd floor, 2nd graders on the 3rd floor, and 3rd graders on the 4th floor in the same way as the current classroom layout. Male students were placed in classes 1 to 5, and female students in classes 6 to 10. Table 4 shows the current status of staffing by class.

Table 4. Status of student placement by class

Class / Grade and Gender			Class											
			1	2	3	4	5	6	7	8	9	10	Subtotal	Total
Number of students	1st grade	Male	29	29	28	27	26	-	-	-	-	-	139	279
		Female	-	-	-	-	-	28	28	28	28	28	140	
	2nd grade	Male	24	23	26	26	25	-	-	-	-	-	124	260
		Female	-	-	-	-	-	23	23	21	34	35	136	
	3rd grade	Male	20	21	27	27	28	-	-	-	-	-	123	276
		Female	-	-	-	-	-	29	29	29	33	33	153	

2.2.2 Performance-oriented design criteria

For the number of students assigned to classrooms, the 「Performance-oriented Design Method and Criteria for Firefighting Facilities, etc.」 of "density of occupants by usage type according to the use of buildings subject to evacuation safety zones" was applied. [9], [10]

The classroom area currently used by the school is 1,995.99m². If the classroom area in use is calculated based on 1.9m²/person, which is the standard for calculating the capacity of 「Firefighting facilities, etc. performance-oriented design methods and standards」, the capacity is 1,050 people. Table 5 shows the current status of student placement by class according to the performance-oriented design method to measure the change in evacuation simulation according to the increase in the number of students.

Table 5. Status of student placement by class according to the performance-oriented design method

Class / Grade and Gender			Class											
			1	2	3	4	5	6	7	8	9	10	Subtotal	Total
Number of students	1st grade	Male	34	34	34	34	34	-	-	-	-	-	170	350
		Female	-	-	-	-	-	34	34	34	34	44	180	
	2nd	Male	34	34	34	34	34	-	-	-	-	-	170	350

	grade	Female	-	-	-	-	-	34	34	34	34	44	180	
	3rd grade	Male	34	34	34	34	34	-	-	-	-	-	170	350
		Female	-	-	-	-	-	34	34	34	34	44	180	

2.3 Input variables and input values

The physical characteristics of the occupants that act as major variables in the evacuation simulation of Pathfinder, which was used as an analysis tool in this study, include walking speed, shoulder width, and height. [11] Shoulder width and height were organized by grade by reflecting the body size of the Korean anthropometric survey by applying the standard body type by gender and age. In the case of faculty members, the average value of those in their 20s or older was applied, [12], [13] and the average walking speed of adults, 1.19 m/s, was applied. [14] The results of organizing the input variables and input values are shown in Table 6.

Table 6. Input variables and input values

Input variables			Input values
Walking speed (m/s)			1.19
Distance between two edges of shoulders (cm)	1st grade (17-year-old)	Male	41.6
		Female	37.7
	2nd grade (18-year-old)	Male	41.6
		Female	37.7
	3rd grade (19-year-old)	Male	42.5
		Female	37.5
	Faculty	Male	48.2
		Female	38.8
Height (cm)	1st grade (17-year-old)	Male	172.6
		Female	159.8
	2nd grade (18-year-old)	Male	173
		Female	159.4
	3rd grade (19-year-old)	Male	173.1
		Female	159.8
	Faculty	Male	173.9
		Female	160.4

2.4 Configuration of scenario and setting of evacuation time

The fire is set to have occurred in the administrative office on the first floor, scenario composition was divided into 8 parts. In the scenario, in the event of a disaster such as a fire, according to the change in the width of the corridor, students use the left stairway exit (S1) and right stairway exit (S2) at the top of the school building, and the left stairway exit (S3) and right stairway exit (S4) at the bottom of the building. REST was the evacuation time when all students finally passed through the exit on the first floor. In establishing the scenario for measuring the change in evacuation time according to the increase in corridor width, Article 15-2 Paragraph 1 of the 「Regulations on Standards for Evacuation and Fire Protection Structures of Buildings」 was applied accordingly. For the width of the hallway in Scenario 1, when the total floor area of the living room on the floor is 200 square meters or more, the rule of 1.5m or more, which is the width of the hallway with living rooms on both sides, was applied mutatis mutandis. The width of the hallway in Scenario 2 was set to 1.8m or more, which is the standard for hallways in other high schools, and the width of the hallway in Scenario 3 was set to 2.4m or more, which is the width of a hallway with living rooms on both sides of a high school. In Scenario 4, the width was set at 3.0m as the corridor of the current school. Regarding the calculation of the occupancy in scenarios 5 to 8, the total classroom area of 1,995.99m² is calculated based on 1.9m²/person, which is the standard for calculating the occupancy of the "performance-oriented design method and standard for firefighting facilities, etc." The capacity was calculated on the basis of 1,148 students, which is 1,050 students plus 98 faculty members. In calculating RSET, the time required to recognize a fire and the evacuation time from recognizing a fire to initiating evacuation are important variables. In this study, evacuation after 60 seconds was set by referring to the contents of offices, commercial and industrial buildings, schools, and universities among the evacuation time standards of 「Methods and standards for performance-oriented design of firefighting facilities, etc.」.

Table 7. Composition of scenario

Category	Corridor width	Occupant capacity	Evacuation time	Remark
Scenario 1	1.5m	913 people	60 seconds	「Rules on Standards for Evacuation and Fire Protection Structures of Buildings」 The total floor area of the living room on the floor is 200m² or more Corridor with living rooms on both sides
Scenario 2	1.8m	913 people	60 seconds	Corridor without living rooms on both sides
Scenario 3	2.4m	913 people	60 seconds	Corridor with living rooms on both sides
Scenario 4	3.0m	913 people	60 seconds	Existing
Scenario 5	1.5m	1,148 people	60 seconds	「Rules on Standards for Evacuation and Fire Protection Structures of Buildings」 The total floor area of the living room on the floor is 200m² or more Corridor with living rooms on both sides
Scenario 6	1.8m	1,148 people	60 seconds	Corridor without living rooms on both sides
Scenario 7	2.4m	1,148 people	60 seconds	Corridor with living rooms on both sides
Scenario 8	3.0m	1,148 people	60 seconds	Existing

3. Experimental results and analysis

The main analysis section in this study to measure the change in evacuation time according to the change in corridor width was set near the right stairway exit (S2) on the top of the second floor of the building. The vicinity of the right stairway exit (S2), set as the main analysis section, is a section where people on the 3rd and 4th floors and people on the 2nd floor descend toward the exit meet together, and the crowd density increases.

The results of the evacuation simulation for scenarios 1 to 4, in which the same number of people were assigned as the current school personnel arrangement, are as follows. It took 389.28 seconds for a corridor width of 1.5 m, 418.78 seconds for 1.8 m, 358.28 seconds for 2.4 m, and 346.53 seconds for 3.0 m. appeared to be the shortest.

Table 8 is for the comparative analysis with the scenario 2, which has the longest time for the evacuation. This is the result of comparison and analysis of the evacuation time and difference in the evacuation time between scenario 2 with the longest evacuation time and the scenario 4 with the shortest evacuation time of 346.53 seconds to compare the number of people who couldn't evacuate at the moment of 346.53 seconds. Depending on the evacuation time, it can be confirmed that the number of occupants not evacuated at 346.53 seconds decreases.

Table 8. The number of occupants unable to evacuate at 346.53 seconds and the difference in evacuation time from Scenario 2

Division	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Required time to evacuate(sec)	389.28	418.78	358.28	346.53
Difference between scenario 2 and evacuation time(sec)	29.5	-	60.5	72.25
Number of persons unable to evacuate at 346.53 sec(persons)	40	46	9	0

In the case of Scenarios 1 and 2, the bottleneck occurred 60 seconds after the evacuation was initiated and was maintained until about 135 seconds. On the other hand, in case of Scenarios 3 and 4, as many people gathered as the width of the corridor was wide, the instantaneous crowd density was higher than that of Scenarios 1 and 2, but showed a rapidly decreasing trend. The maximum cluster density of scenario 1 was 2.33 people/m2, scenario 2 was 2.51 people/m2, scenario 3 was 2.59 people/m2, and scenario 4 was 2.73 people/m2. The trend of the cluster density of scenarios 1 to 4 is shown in Fig. 2.

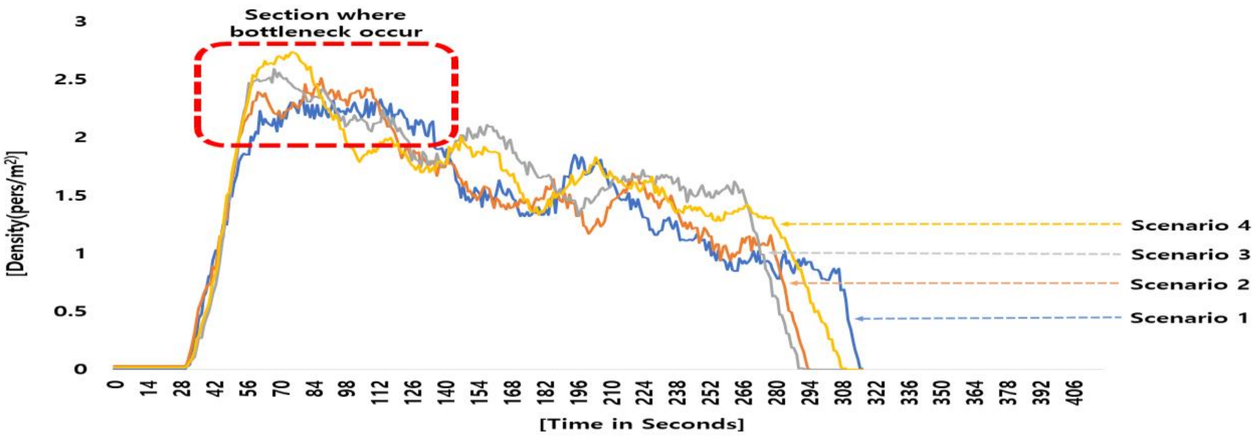


Figure 2. Trends in Cluster Density in Major Bottlenecks

The results of evacuation simulations for scenarios 5 to 8, in which personnel are assigned based on the capacity calculation standard of 1.9m²/person in 「Methods and standards for performance-oriented design of firefighting facilities, etc.」, are as follows. Scenario 5 with the corridor width set to 1.5m takes 445.28 seconds, Scenario 6 with the corridor width set to 1.8m takes 498.53 seconds, Scenario 7 with the corridor width set to 2.4m takes 433.53 seconds and the corridor width set to 3.0m, and Scenario 8 took 418.53 seconds. Therefore, the evacuation time was found to be the shortest at 3.0m, the widest corridor.

Table 9 is for the comparative analysis with the scenario 6, which has the longest time for the evacuation. This is the result of comparison and analysis of the evacuation time and difference in the evacuation time between scenario 6 with the longest evacuation time and the scenario 8 with the shortest evacuation time of 418.53 seconds to compare the number of people who couldn't evacuate at the moment of 418.53 seconds. The difference in evacuation time from scenario 6 was 80 seconds in scenario 8, 65 seconds in scenario 7, and 53.25 seconds in scenario 5.

Table 9. The number of occupants unable to evacuate at 418.53 seconds and the difference in evacuation time from Scenario 6

Division	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Required time to evacuate(sec)	445.28	498.53	433.53	418.53
Difference between scenario 6 and evacuation time(sec)	53.25	-	65	80
Number of persons unable to evacuate at 418.53 sec(persons)	23	50	13	0

In the case of scenario 5, the maximum cluster density does not appear as high as in other scenarios, but the cluster density was maintained at a certain level and then decreased. Scenarios 6 to 8 showed the same pattern as scenarios 1 to 4, in which the same number of students was assigned as the current school personnel arrangement. Scenarios 7 and 8, where the width of the corridor was wide, showed the highest cluster density, followed by a rapid decrease in cluster density.

On the other hand, in scenario 6, the maximum cluster density was not higher than that of scenarios 7 and 8, but the cluster density was maintained and then decreased.

Scenario 5 had a maximum cluster density of 2.15 people/m2, scenario 6 of 2.51 people/m2, scenario 7 of 2.73 people/m2, and scenario 8 of 2.91 people/m2. The trend of the cluster density of scenarios 5 to 8 is shown in Fig. 3.

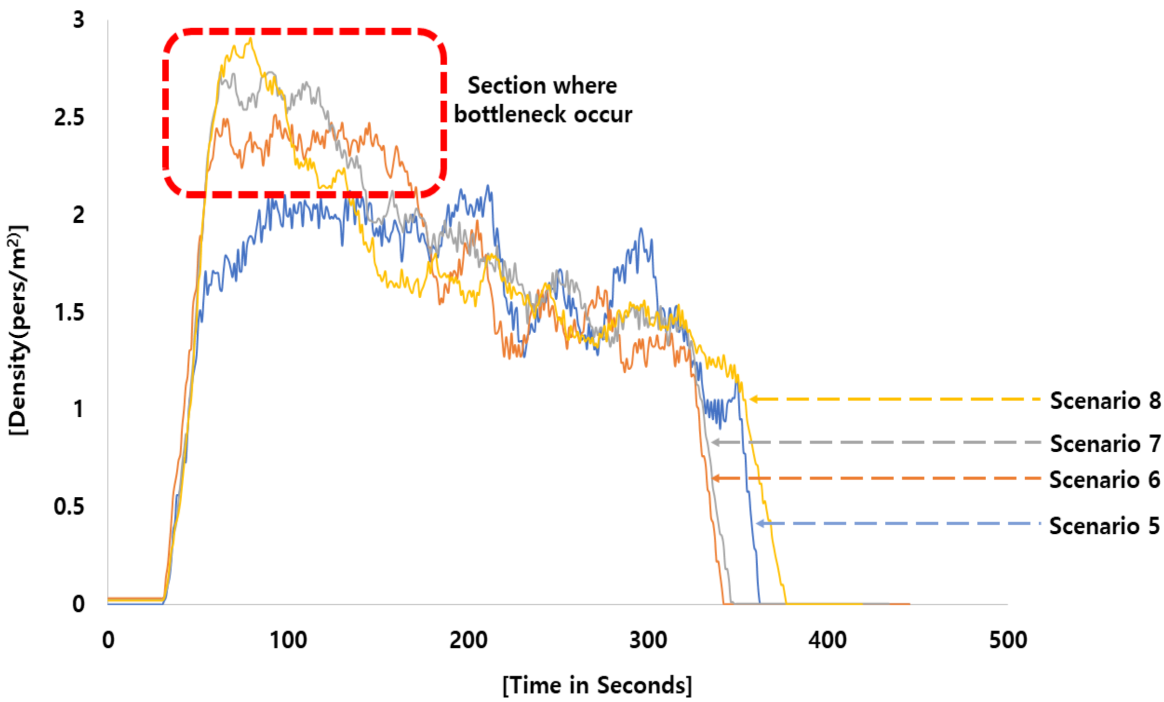


Figure 3. Trends in Cluster Density in Major Bottlenecks

4. Conclusion

In order to analyze the evacuation safety according to the change in the corridor width of the high school, for the same number of students as the current school, in this study, evacuation simulations were conducted according to the corridor width and installation standards stipulated in Article 15-2 of the 「Regulations on Standards for Building Evacuation and Fire Protection Structure」 and the width of the corridor of the present high school. Afterwards, in order to analyze the evacuation time according to the increase in the number of occupants and the change in the width of the corridor, an evacuation simulation was conducted by applying the scenario writing standards set forth in the calculation standards for the number of occupants in 「Methods and standards for performance-oriented design of firefighting facilities, etc.」 .

The results derived from each experiment are as follows.

(1) Scenario 4 took 346.53 seconds when the corridor width was the widest, 3m. Scenario 8 took 418.53 seconds, showing the fastest evacuation time.

(2) In the case of a corridor width of 1.8m with no living room on either side, it took 418.78 seconds in scenario 2. Scenario 6 took 498.53 seconds, showing the slowest evacuation time.

This study has limitations in that it conducted an evacuation simulation upon the targeted high schools in a specific region and did not compare and analyze the results of the experiment with the one from actual evacuation drills. However, it is meaningful in that the evacuation safety evaluation was confirmed by comparing and analyzing the results of evacuation simulations to ensure the safety of high school students who spend most of their time at school. Changes in physical evacuation density in the event of a fire in a building are correlated with the evacuation speed of students. The shorter evacuation times in scenarios 3 and 4 and scenarios 7 and 8 with wide corridors confirm the results of previous studies that argued that the width of the corridor is an important factor in determining the speed and density of students during evacuation. [15] On the other hand, the evacuation time of scenarios 2 and 6 was found to be longer than that of scenarios 1 and 5, which have the narrowest corridor widths. This is a result that confirms that fire safety education is an important factor in schools with narrow corridors. In a study by Jeong-soo Lee and Heung-soon Kwon (2012), it was found that the factors that have the greatest influence on students' evacuation behavior are cognitive factors such as evacuation methods and knowledge of exit locations, rather than physical factors. [16] In an emergency situation such as the occurrence of a disaster, there is a relatively high possibility of evacuating by choosing an exit that is familiar even if it takes longer, even if the person is aware of the existence of an unfamiliar fast exit due to his or her irrational judgment in an emergency. [17] Through this, it can be confirmed that the correct response plan according to the emergency situation is the most important factor in the event of a fire. Therefore, evacuation time can be shortened and varied according to repeated and continuous evacuation drills. In the case of schools with narrow corridors, it is necessary to understand the location and use of emergency exits through practical evacuation drills at least once a month. Since there is no advance notice in an accident, it is very necessary to conduct evacuation drills and cognitive training in preparation for emergency situations.

In the future, additional analysis on evacuation safety comparing ASET (Available Safety Escape Time) calculated by conducting fire simulation analysis for schools conducted in this study and REST (Required Safety Escape Time) derived from this study will be needed.

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