Analysing the Effects of Sales Stand Installations on Evacuation Dynamics in Indoor Sports Blocks

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Abstract
Indoor sports clubs, gymnasiums, and sports blocks and complexes have the potential for causing significant casualties in the event of a fire. As a result, there is a significant amount of research being done on fire safety. The impact of sales stands on fire safety is a vital aspect that needs to be considered to ensure comprehensive safety measures. This study seeks to assess the effect of sales stands on the time it takes to evacuate indoor sports blocks in the event of a fire. A fire and evacuation simulation programme were utilised to analyse the characteristics of fire and evacuation. The findings indicated that the sales stand had an impact on the time it took for sports athletes and physical workers to complete the evacuation, particularly when the corridor width was wide. However, there was no significant effect observed when the hallway width was narrow. Instead, they expanded the congested area in the hallway, resulting in a longer resolution time. It is evident that sales stand in indoor sports blocks and sports centres or complexes could potentially jeopardise evacuation safety. This study can serve as a basis for implementing safety measures. It examines how obstacles in corridors, such as those found in schools and hotels, impact the evacuation behaviour of individuals. These findings are particularly relevant for indoor sports facilities, which share similar spatial characteristics.
Keywords: Indoor Sports Blocks, Urbanization, Evacuation Duration, Fire Outbreak, Protruding Sales Stand.

1. Introduction

In Korea, the continuous growth of industrialization and urbanisation since the 1960s has led to an increased demand for urban development zones. Utilising indoor spaces has become a practical solution to effectively address these demands. A variety of stores have been constructed within the indoor areas to cater to customers' needs, offering clothing, cosmetics, accessories, and dining options. It is used for a range of purposes, including transportation, cultural activities, sports, and entertainment facilities (Seo, 2013). Based on a global fitness statistics report, the global interest rate has been steadily rising at a rate of 8.7% per year. This highlights the importance of sports complexes and centres (IHRSA, 2020). Therefore, it is imperative for these facilities to prioritise the provision of top-notch services and robust security systems to ensure the safety and well-being of athletes, guarding against any unfortunate incidents or accidents (Majd et al., 2021).

In the event of a fire in an indoor space, it has the potential to rapidly spread to neighbouring stores due to the space compartments within the sports centres. Furthermore, restaurants are near sports centres and various sports complexes on the outskirts. These areas house significant quantities of highly flammable materials, including clothing and cosmetics, thereby posing a considerable risk of human casualties in the event of a fire (Hursa Šajatović, Flinčec Grgac, & Zavec, 2022). Significant casualties can occur in enclosed spaces because of the smoke and limited visibility brought on by outside air, as well as the chaotic nature of emergency situations (Cao et al., 2019; Jeon et al., 2011). This is due to people losing their sense of direction (Helbing, Johansson, & Al-Abideen, 2007), the confusion caused by overlapping smoke and evacuation directions (An, Kang, & Lee, 2004), the limited number of evacuation routes, and congestion at entrances (Haghani & Sarvi, 2016).

Past research has examined evacuation safety measures in indoor areas, specifically focusing on the use of risk and disaster prevention facilities for fire outbreaks. According to Jeon et al., the presence of smoke can hinder visibility and slow down the evacuation process, ultimately increasing the time it takes for people to escape (Jeon et al., 2011). Wang et al. developed a numerical analysis model for fire evacuation in IUCB (IRCB) using agents. They examined evacuation strategies and evacuation times and provided helpful tips and guidelines for IUCB fires (Nazir

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et al., 2021). The authors provided guidelines and criteria for safeguarding life and property from fires and explosions in indoor spaces. They also conducted an analysis of the factors that need to be taken into account when developing an evacuation plan for indoor areas (Wang et al., 2021).

An analysis was conducted on the fire characteristics and smoke management phenomena in indoor, closed, and underground spaces, specifically focusing on the operation of the fire protection system. Through fire simulation, it was determined that the fire shelter played a crucial role in ensuring evacuation safety. Based on these findings, a method of improvement was proposed (Viegas et al., 2021). Numerous studies have been conducted on safety performance and management, employing various approaches (Khalid, Sagoo, & Benachir, 2021; Viegas et al., 2021). Previous research has explored a range of perspectives, but there is a lack of studies specifically examining the factors that impact evacuees in indoor sports complexes and blocks. Thus, this study aimed to enhance evacuation safety in indoor sports blocks and complexes.

This study examines the effect of sales stands on evacuation time in indoor sports blocks during a fire using fire and evacuation simulations. The study primarily examines the original state and layout of the indoor sports blocks and complexes during their construction, rather than their current configuration. The study considers the influence of sales stand parameters, corridor width, and hallway width on the time it takes to complete an evacuation.

To fulfil the mentioned responsibility, the study has utilised an experimental approach and focused on observing the sports complexes and training centres in the metropolitan city of Busan. The research aimed to demonstrate the significance of sales stands in evacuation times, considering various factors. It also aimed to provide new insights for practitioners and authorities in indoor sports complexes, as well as other public settings like sports malls, restaurants, and hospitals. The study emphasised the importance of understanding the critical components associated with fire evacuation and the need for a well-planned setup to ensure a swift evacuation.

2. Literature Review

2.1. Sports Complexes and their Importance in the Customers' Viewpoints

Sports complexes serve as comprehensive hubs for all sports-related facilities. Sports complexes typically offer a range of facilities, including soccer fields, swimming pools, indoor stadiums, athletic fields, and baseball fields (Accelerator, 2023). Sports complexes typically feature a variety of infrastructure structures. Many of these complexes are open-air, lacking ceiling boundaries. This setup is particularly common in stadiums (Jiang, Yin, & Cui, 2020). In addition to the expansive outdoor stadiums, there has been a noticeable rise in the development, promotion, and utilisation of indoor sports stadiums or centres.

These facilities serve as the hub for various equipment and services necessary for physical exercise. In indoor sports settings, a wide range of services are available. These include physical fitness options such as cardio equipment like stationary exercise bicycles, rowing machines, elliptical trainers, treadmills, and weight-based exercise machines. Additionally, there are group exercise services where instructors and physical guides offer classes and sessions in cycling/spinning, aerobics, step yoga, and stretching. From a sports perspective, these facilities also provide indoor running tracks, squash courts, baseball courts, ice rinks, and swimming pools (Blocken et al., 2020).

Indoor sports stadiums and complexes offer a wide range of facilities under one roof, attracting many visitors. These indoor spaces are highly popular due to the quality services they provide. Even individuals with physical disabilities show a significant interest in visiting and engaging with sports in these centres (Ponchillia et al., 2020). The customers' perceptions are not the only factor influencing sports. The era of urbanisation and high advancement also plays a significant role. A study conducted a comparison analysis on the extensive practice of urbanisation and the construction of sports hubs for hosting province-level games. This urban spatial structure, which is wide, highly invested, and expansive, provides a real-life representation of the widespread prevalence of sports activities at all levels (Fan et al., 2021).

2.2. Services and Security system Quality Importance: A general Insight

The security services provided by indoor sports complexes and centres have a significant impact on customer preferences, loyalty, and sports involvement. Physical safety is identified as a crucial security service that any sports centre should offer. Additionally, factors such as security personnel qualifications and accreditation, sports facility structure, communication, protection against toxic substances, environmental control, education of emergency management, risk management, entrance control, and cultural practices also contribute to the overall security of these facilities (Majd et al., 2021). The importance of maintaining a strong understanding and control over quality systems in relation to physical safety cannot be overstated. Extensive research has shown that both the psychological and physical safety of individuals have a significant influence on their knowledge, loyalty, and attachment as customers and athletes (Behnam et al., 2021).

2.3. Security System, Fire excavation and Sports Indoor Complexes

Fire excavation in accident management is a crucial service that has been extensively studied. Numerous studies have provided valuable insights, effective measures, and strategies for efficiently managing fire incidents. This system is widely discussed due to its direct impact on casualties and collateral damages. An empirical investigation was conducted to analyse the effective measures that can reduce the negative consequences of fire incidents, specifically the casualties. The study employed a systematic review approach. Upon compiling the results, it was found that the technology awareness, operational management, resource efficiency, and robust safety measures of the population in the accident building have a significant mitigating effect on casualties and financial loss (Soltaninejad, Faraji, & Noorzai, 2021).

Furthermore, another study presented a fresh perspective by discussing a comprehensive disaster management system designed to ensure the safety of tourists. The research identified a system that facilitates effective communication between site managers, tourists, and visitors. It also highlighted the inclusion of early warning mechanisms for various natural disasters such as wildfires and floods. Ultimately, the study underscored the importance of the primary element of the examined catastrophe. The management system served as an early alert message and an indication of an acciden (Psaroudakis et al., 2021).

In a study conducted by Rathnayake and Sridarran, they examined the various factors that contribute to the occurrence of fire incidents in general buildings. Through an extensive review of literature, the study identified several key factors, starting with building design features and continuing with refurbishment practices, fire regulations, policies, and building codes. Additionally, the study explored firefighting tools, techniques, and the perspectives of architects and constructors, as well (Rathnayake, Sridarran, & Abeynayake, 2020).

There is a scarcity of studies in the literature, especially in the field of sports. However, there are a few empirical justifications that can shed light on the topic at hand. A study conducted by Bodur (2021) has examined the significance of the fire excavation system in a renowned hall in Turkey that has served various purposes for many years. The study emphasises the multi-dimensional usage and importance of the sports hall, highlighting the necessity of escape ladders and compartments; and it is important to consider systems that address detection, warning, alertness, early indication, and guidance when implementing preventive measures against fires. Furthermore, it is essential to provide explicit entry and exit directions using arrows due to the significant influx and outflow of people during the activity. Additionally, to ensure the safety of the building, it is crucial to implement stringent measures to prevent the occurrence of fires in the sports halls and complexes.

A recent study examined the use of steel structures in sports centres as a means of preventing significant damage in the event of a fire. Through chemical and microstructural analysis, the study confirmed the effectiveness of incorporating steel structures as a defensive measure in sports halls. This measure can help mitigate financial losses and minimise damage to the building structure in the event of a fire outbreak (Blanc, Sánchez, & Navarro, 2022). Several studies have explored various factors that can help prevent fire outbreaks. However, there is a lack of empirical evidence regarding specific integrated systems, building styles, or fire-evacuation setups in sports complexes with indoor setups. This study aims to address this gap by examining the impact of sales stands and building construction elements on the evacuation time and population density during a fire in sports complexes.

3. Research Process

3.1. Pathfinder Software

For this study, we have chosen to use Pathfinder, a powerful evacuation simulation tool, to conduct our simulations. Pathfinder is a cutting-edge agent-based evacuation simulation software developed by Thunderhead. This model is a 3D triangular mesh-based representation that effectively captures intricate geometric details and curves. One benefit of this approach is that it allows for more realistic movement, as opposed to the Fine Network method which relies on grid-based calculations. Specifically, it serves as a microscopic model for predicting overall evacuation by considering individual behaviour. It also can visualise bottlenecks and congestion, thanks to its enhanced 3D space visualisation and consideration of various mobility phenomena. This sets it apart from other models (Li et al., 2022).

Furthermore, through an analysis of the existing indoor sports complexes and various sports training centres in Busan Metropolitan City, this study focuses on identifying the indoor sports complexes that may pose the greatest challenges during an evacuation. The number of evacuees was determined by referencing the criteria for the density of occupants by usage suggested in Korea and used as an input value for the evacuation simulation. In regard to the experiment conditions, the number of evacuees, as well as their initial position and walking speed, were all standardised. This was done to ensure consistency across the different scenarios, depending on whether a stand was installed or not. A sports facility without a stand in the hallway was categorised as Case 1, while a sports complex with a stand was categorised as Case 2. Upon calculating the evacuation time in various areas such as bottlenecks, passages, stairs, and entrances using a simulation tool, we then compared and analysed the resulting values to understand the variations in the evacuation characteristics of indoor sports complexes. The process utilised in this study is summarised in Figure 1.

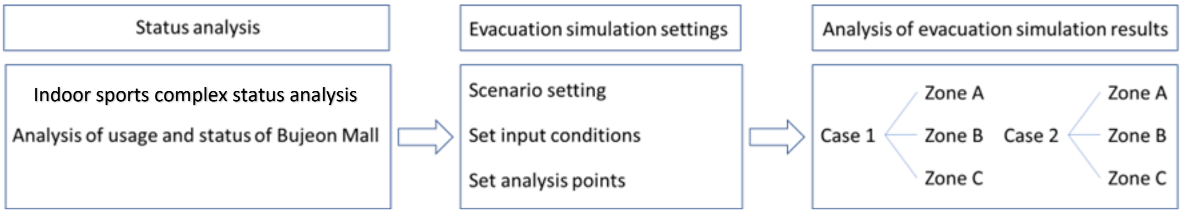

Figure 1. An Overview of Research Methodology to Perform the Present Work.

3.2. Evacuation Completion Time Setting

The evacuation completion time was determined using the Society of Fire Protection Engineers (SFPE) Handbook, as follows: (SFPE, 2016)

$$RSET = t_{det} + t_{res} + t_{mov} \quad (1)$$

Where $RSET$ is the evacuation time, t_{det} is the time required to detect the fire, t_{res} is the time required for the alarm equipment to respond and operate after sensing the signal and the time required for the restart personnel to recognize the fire (using the alarm equipment), and t_{mov} consists of the time required for the restart personnel to start and complete the evacuation. The time it takes to evacuate during a fire situation is determined by the effectiveness of the detection system. Figure 2 illustrates the overall framework for safety protocols in case of a fire. However, this study examines the impact of the stalls that extended into the hallway on the evacuation characteristics of the agents. It is important to note that the safety protocols for evacuating indoor sports complexes were followed, specifically in relation to fire safety. As a result, the time taken from the start to the end of the evacuation process was deemed as the "evacuation time."

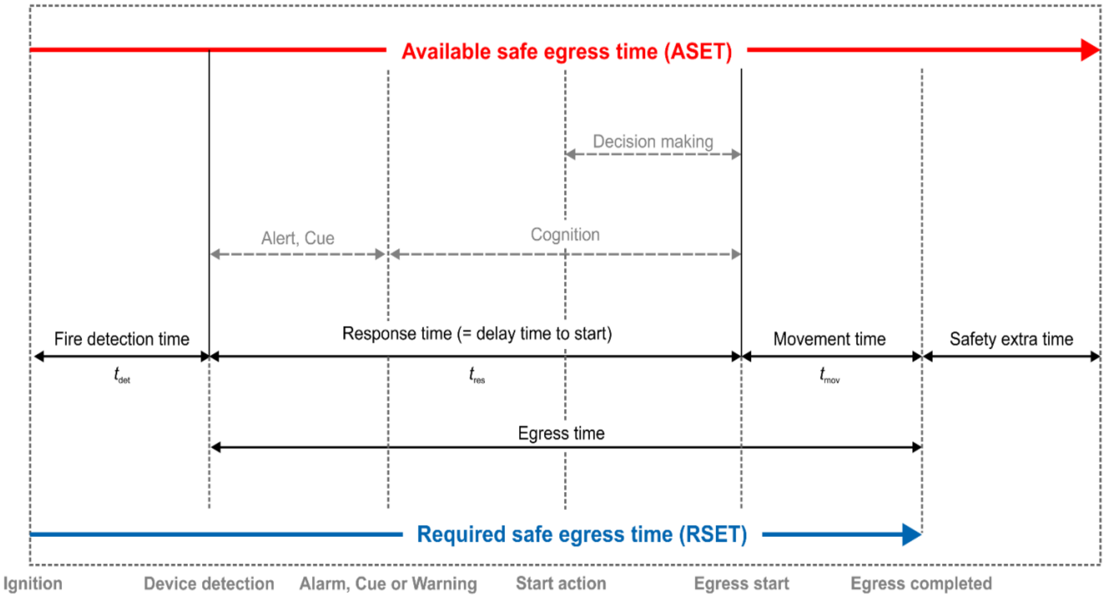

Figure 2. Composition of Evacuation Time; Available Safe Egress Time (ASET), Fire Detection Time (t_{det}), Response Time (t_{res}), Movement Time (t_{mov}), and Required Safe Egress Time (RSET).

3.3. Simulation Input Conditions and Analysis

As depicted in Figure 3, two cases have been considered for this study. For Case 1, we will consider the indoor sports complexes at the time of construction, without any sales stands installed. In Case 2, the current state of the indoor mall, where the sales stands have been installed, is considered. The specification of the stand installed in the corridor in Case 2 was set to 1.3 m (width) × 0.7 m (thickness). The number of agents was based on 3051 people in the store and 867 corridors, depending on the re-implementation density (store1 m^2/person, aisle m^2/person), as presented in the "Special Act on Disaster Management of Super High-Rise and Indoor Buildings" in Korea. However, given the higher concentration of people in the hallway compared to the store, some store personnel are positioned on the aisle side, close to the shelves where the products are showcased.

The walking speed of agents is determined by factors such as gender and age, as discussed in the research paper "Prevention of Fire Expansion and Development of Evacuation Safety Design Technology according to Standard Fire Model". All agents were set to a height of 172 cm and a walking speed of 1.2 m/s, based on the average height and speed of Korean men. Afterwards, the number of agents, initial location, height, and walking speed for each case were all set to identical values. At the start of the simulation, all the agents engaged in a one-on-one evacuation.

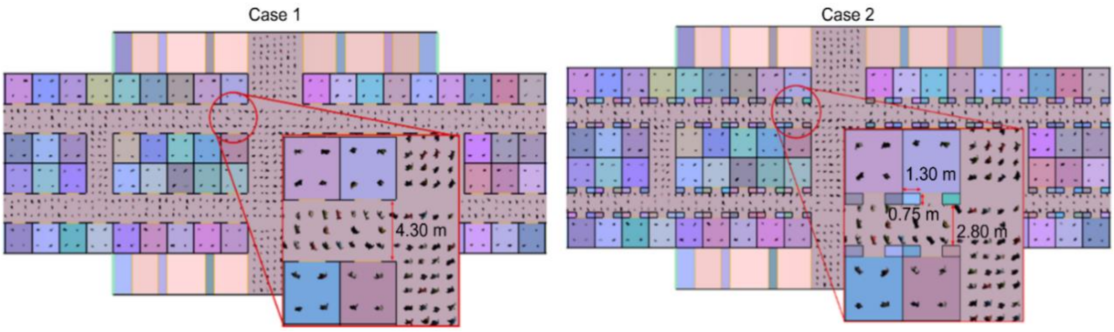

Figure 3. Corridor Status of One of the Targeted Sport Complexes (a) Case 1, With No Installed Stalls; (b) Case 2, With Installed Stalls.

Figure 4 displays the simulation analysis results for Case 1 and Case 2. To analyse the characteristics of agent evacuation in each case, the areas were divided into three sections: A, B, and C. These sections include the entrance of stairs, the stairs themselves, and the surrounding corridor area where the stairs connect to the ground. Following that, as indicated in Table 1, each area underwent analysis by being divided into a total of four points: the stair entrance ($R_{1,2,3,4,5}-1$), the central part of the corridor connected to the stair entrance ($R_{1,2,3,4,5}-3$), the left hallway ($R_{1,2,3,4,5}-2$), and the right hallway ($R_{1,2,3,4,5}-4$). For the width of the stairs by zone and the width of the corridor ($R_{1,2,3,4,5}-3$), A was set to 8.6 m and 6.0 m, B was set to 4.2 m and 6.0 m, and C was set to 4.2 m and 3.7 m, respectively.

Table 1

Analysis Zones Used in the Simulation.

Zones	Corridor	Corridor Centre Width (m)	Stair	Stair Width (m)
A	R1-1–4 / R2-1–4	8.6	1, 2, 3, 4	6.0
B	R3-1–4 / R4-1–4	4.2	5, 6, 7, 8	6.0
C	R5-1–4	4.2	9	3.7

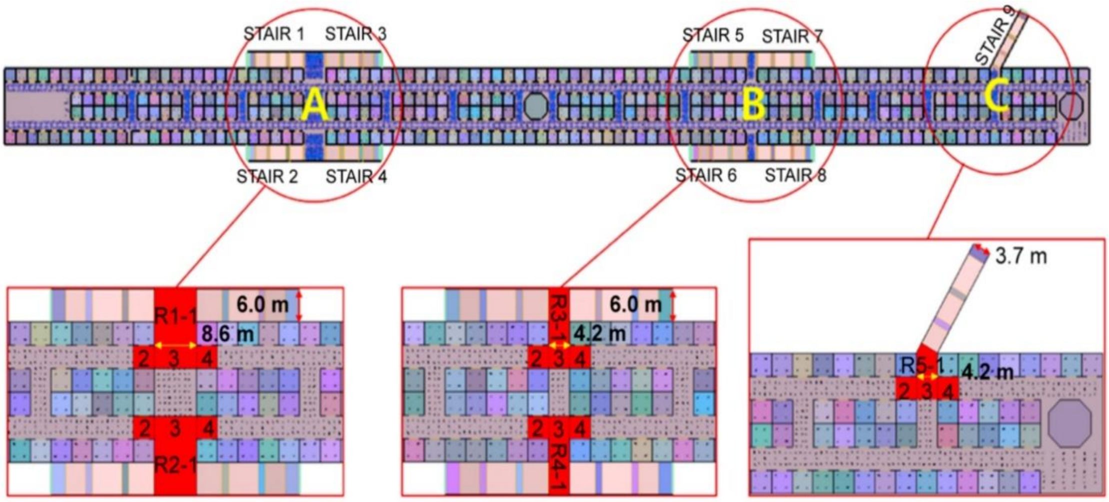

Figure 4. Simulation Agent Evacuation Analysis Points.

5. Results and Discussion

Zone A

Figure 5 provides a separate view of the evacuation situation for the agents in Zone A in both cases. The flow of people on the stairs was seamless in both locations. Regarding corridors, in Case 1, the agents observed a smooth flow (R_(1,2)-3); however, several individuals entered the branch simultaneously and the entrance point was quite spacious, measuring 8.6 metres in width. Thus, in Case 1, the evacuation in the corridor was successfully completed 136.9 s after the start of the evacuation, with no obstructions encountered. However, in Case 2, the narrowing of the hallway caused by the stand results in a decrease in the number of people who can pass through at the same time. Consequently, agents experience a lack of progress along the corridor, leading to delays in their evacuation, despite the absence of bottleneck sections in the hallway.

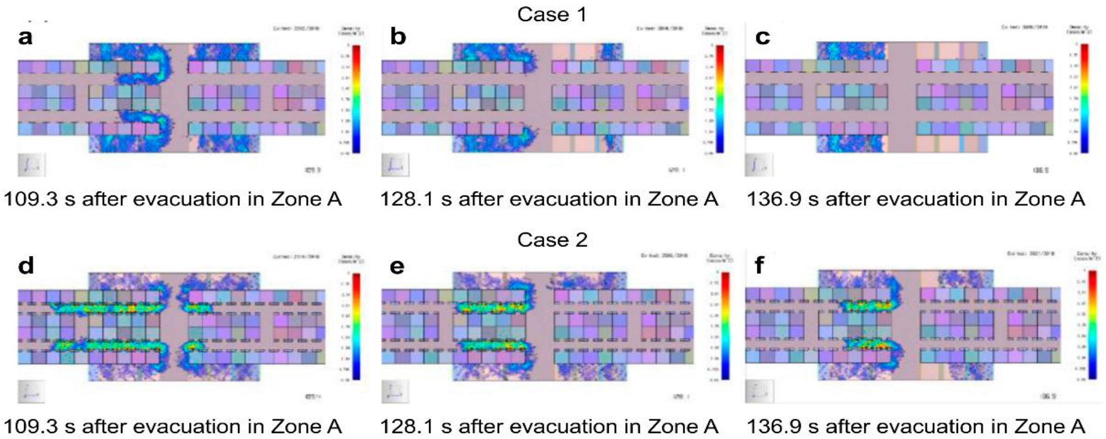

Figure 5. Comparison of Evacuation Situations for Agents for Zone A for Both Cases at Three-time Frames, Namely 109.3 s, 128.1 s, and 136.9 s After Evacuation.

Figure 6 displays the population density at the measurement point in Zone A, categorised by case. The density in the left and right corridors ($R_{1,2}-2$, $R_{1,2}-4$) was 0.9-1.4 per/m^2 in case 1 and 1.1-1.6 per/m^2 in case 2, so case 2 was 23.0 % higher than case 1. This is because the narrower corridor in Case 2 resulted in fewer agents being able to pass through simultaneously, leading to continuous congestion in the corridor. On the other hand, in the case of $R_{1,2}-3$, the number of agents flowing from $R_{1,2}-2$ and $R_{1,2}-4$ to $R_{1,2}-3$ decreases due to the sale. For this reason, the population density appears to be 0.8-1.0 per/m2 in Case 1 and 0.6-0.7 per/m^2 in Case 2. Compared to Case 1, it appears to decrease by 28.0 % in Case 2.

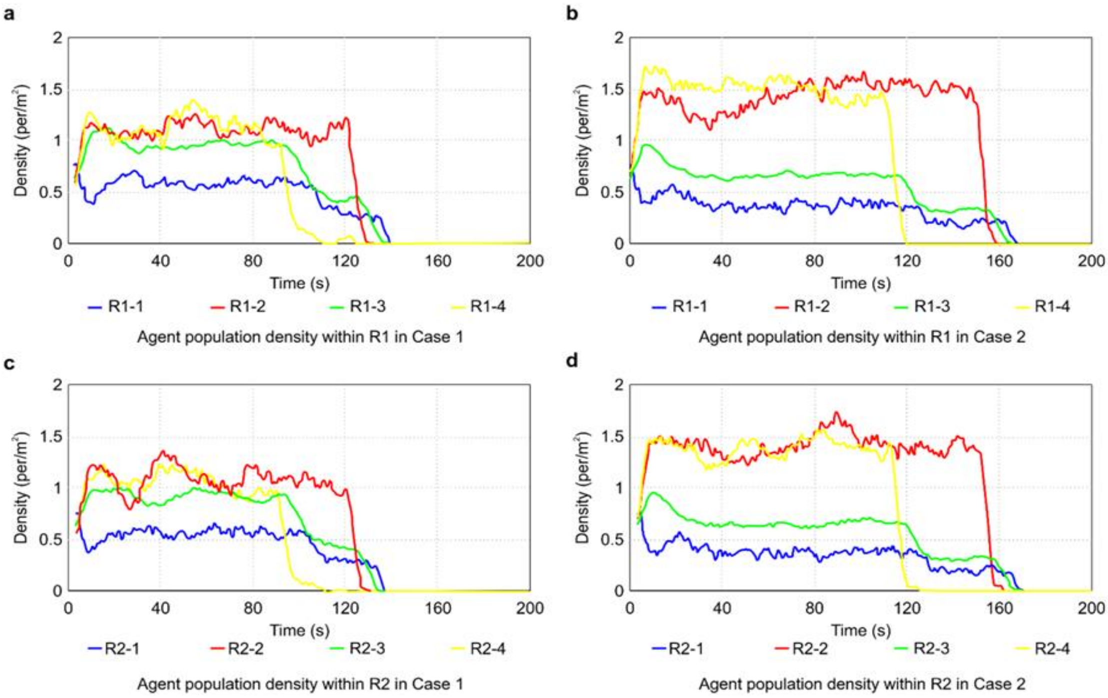

Figure 6. Population Density in Corridors for Zone A for (a and c) Case 1 and (b and d) Case 2.

Table 2

Agent Evacuation Completion Time in Corridors and Stairs by Case (Zone A).

	Category	R1-1	R1-2	R1-3	R1-4	R2-1	R2-2	R2-3	R2-4
Corridor	Case 1 (s)	136	128	130	110	135	128	128	105
	Case 2 (s)	169	161	163	121	166	160	160	118
	Rate of change (%)	▲24.2	▲25.7	▲25.4	▲10.0	▲22.9	▲25.0	▲25.0	▲12.3
Stair	Category	Stair 1		Stair 2		Stair 3		Stair 4	
	Case 1(s)	165		165		139		136	
	Case 2 (s)	196		193		157		154	
	Rate of change (%)	▲18.7		▲17.0		▲12.9		▲13.2	

The agent evacuation completion time in the corridors and stairs in Zone A is summarized in Table 2. Compared to Case 1, due to the installation of stands in Case 2, the evacuation completion time in the hallway increased by 10.0-25.7 % and the evacuation completion time in the stairs increased by 12.9-18.7 %. As a result of analyzing the change in evacuation characteristics in Zone A, when the central part ($R_{1,2}-3$) of the corridor connected to the entrance of the stairs and the width of the stairs are wide, Case 1 shows that multiple agents passing through the left and right corridors ($R_{1,2}-2$, $R_{1,2}-4$) flow smoothly into the stairs. However, in Case 2, the stand restricts the width of the hallway and disrupts the movement of agents passing through the left and right corridors, resulting in longer congestion time in the hallway and increased time for evacuation through the stairs.

Zone B

Figure 7 illustrates the evacuation situation of the agents located in Zone B and the smooth flow of agents at the stairs in both cases. However, in the case of corridors, multiple agents pass through corridors (($R_{3,4}-2$, $R_{3,4}-4$) in Case 1 and flow into $R_{3,4}-3$, so the bottleneck section rapidly forms in the vicinity. After 79.0 seconds from the start of the evacuation, the bottleneck section spreads throughout the hallway. Several agents completed evacuation in the hallway after 127.0 seconds from the start of the evacuation, resolving the bottleneck section. In the scenario of Case 2, the corridor width is reduced because of the stand installation. As a result, the number of agents entering R-3 decreases compared to Case 1, and the bottleneck section forms at a slower pace. Then, as the section with limited capacity expands to the entire hallway, their evacuation process becomes quite lengthy. However, the evacuation from the right hallway is completed at a faster pace than in Case 1, resulting in the gradual resolution of the bottleneck section after 127.0 seconds from the start of the evacuation.

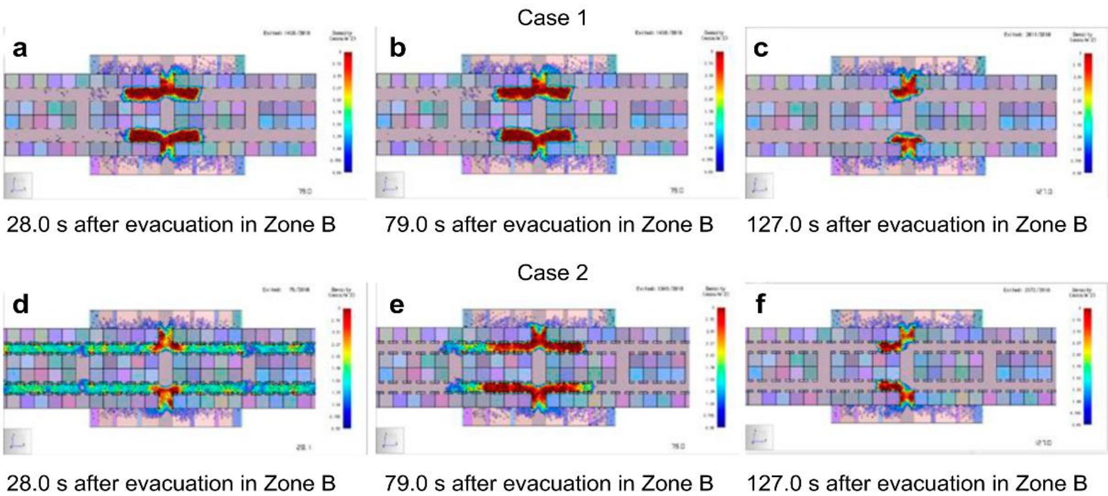

Figure 7. Comparison of Evacuation Situations for Agents for Zone B for both Cases, at Three-time Frames, Namely 28.0 s, 79.0 s, and 127.0 s After Evacuation Initiation.

The population density at the measuring point in Zone B for both cases is presented in Figure 8. In the case of Zone B, because the agents are quickly introduced into the narrow corridor center ($R_{3,4}-3$), the population density within the point for Case 1 was 2.0 per/m2 after 28 s from the start of the evacuation, and the population density for

Case 2 was 2.0 per/m2 after 38 s (forming a bottleneck). As a result of the bottleneck section in R-3, agents are unable to pass through R-2 and R-4, causing them to gather in the area and leading to a higher population density in the hallway. Moreover, due to the impact of the bottleneck in $R_{3,4}-3$, agents did not pass through the point $R_{3,4}-2, R_{3,4}-4$, and the population density in the corridor at the point increased. At this time, the population density was 2.9–3.1 per/m^2 in Case 1 and 2.5–2.9 per/m^2 in Case 2; the density for Case 1 appeared to be approximately 10.0 % higher than for Case 2. This is not only because it is difficult to pass through the hallway due to the bottleneck that occurred in $R_{3,4}-3$, but also because the corridor width of Case 1 is wider than that of Case 2, thus the number of agents flowing into the corresponding point at the same time is large.

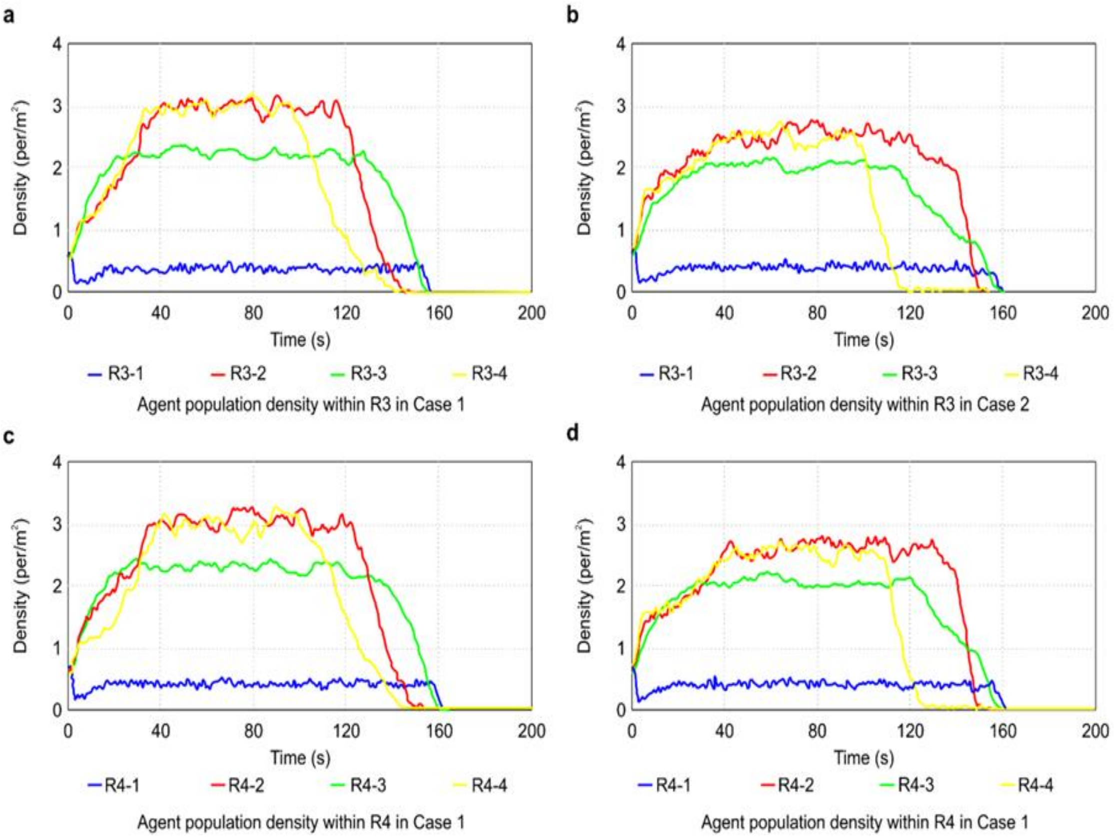

Figure 8. Population Density in Corridors for Zone B for (a and c) Case 1 and (b and d) Case 2.

The completion time for evacuating agents in the corridors and stairs of Zone B is summarised in Table 3. When considering the time it takes to complete an evacuation in the hallway, there is a decrease of -1.6-2.7% in the rate of change at all measurement points except for the right side (R_(3,4)-4) of the hallway.

Table 3

Agent Evacuation Completion Time in Corridors and Stairs for Zone B for Both the Cases.

	Category	R3-1	R3-2	R3-3	R3-4	R4-1	R4-2	R4-3	R4-4
Corridor	Case 1 (s)	156	143	154	141	157	143	154	143
	Case 2 (s)	153	144	151	123	156	147	153	126
	Rate of change (%)	▼1.6	▲0.1	▼1.76	▼12.3	▼0.1	▲2.7	▼0.1	▼11.8
Stair	Category	Stair 5		Stair 6		Stair 7		Stair 8	
	Case 1(s)	181		181		180		179	
	Case 2 (s)	178		182		176		180	
	Rate of change (%)	▼1.7		▲0.1		▼2.2		▲0.1	

However, in the case of the right side ($R_{3,4}-4$) of the hallway, Case 2 appears to decrease by 11.8 to 12.3 % compared to Case 1. In Case 1, multiple agents simultaneously flow into $R_{3,4}-3$ through the right hallway ($R_{3,4}-4$), and thus flow in the right hallway is not smooth; whereas in Case 2, the width of the corridor decreases the number of agents simultaneously flowing from $R_{3,4}-4$ to $R_{3,4}-3$ which enables the continuous inflow of agents. On the other hand, the evacuation completion time on the stairs shows a lower rate of change of approximately -2.2~0.1 % in Case 2 compared to Case 1, implying that the sale stand does not have a significant effect on the change of the evacuation completion time on the stairs. As a result of analyzing the change in evacuation characteristics at Zone B, if the central part ($R_{3,4}-3$) of the corridor connected to the entrance of the stairs is narrow and the width of the stairs is wide, both cases form a bottleneck around $R_{3,4}-3$ and expand to the entire corridor. On the other hand, agents in Case 2 tend to spend more time in the hallway compared to those in Case 1. Case 2 has a smaller corridor width compared to Case 1, resulting in a decrease in population density due to the limited inflow into($R_{(3,4)}$-3) simultaneously. Consequently, the time it takes to complete the evacuation at ($R_{(3,4)}$-4) decreases, while there is no notable variation in the other analysis points. Furthermore, there has been no notable alteration in the time it takes to complete the evacuation via the stairs.

Zone C

The evacuation situation of the agents situated in Zone C for both scenarios is depicted in Figure 9. Both cases showed that there were issues with the flow of people in the stairs and corridors. In Case 1, a congestion point emerged at 14 seconds into the evacuation when agents simultaneously entered R5-3 from three different directions.

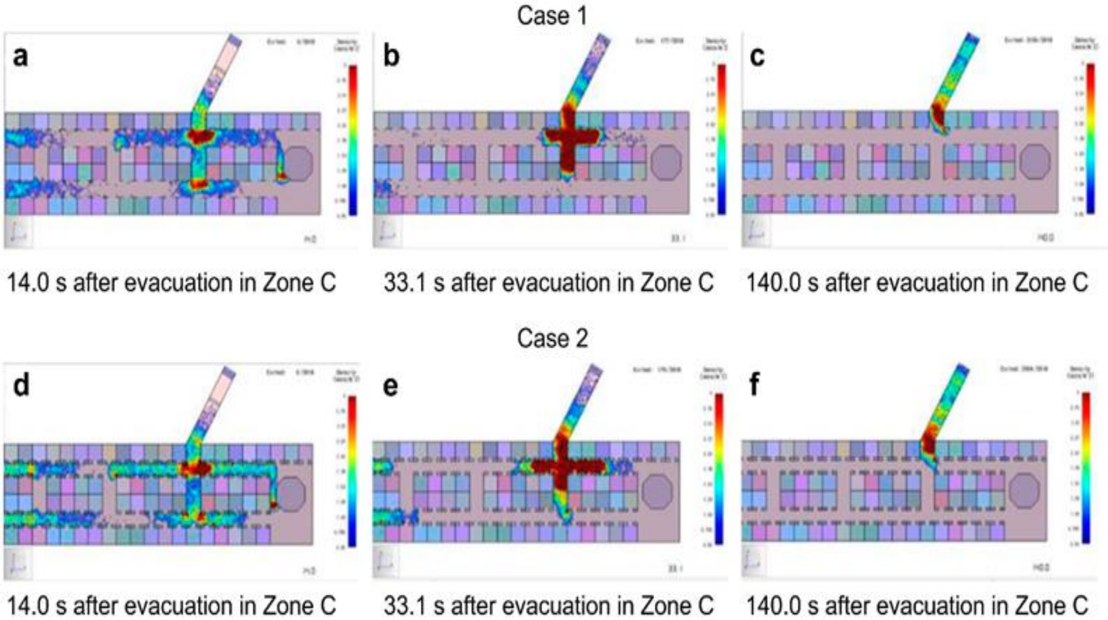

Figure 9. Comparison of Evacuation Situations for Agents for Zone C for Both Cases, at Three-time Frames, Namely 14.0 s, 33.1 s, and 140.0 s After Evacuation Initiation.

As the evacuation progressed, there was a bottleneck at the entrance of the corridor that extended to all sections and stairs. However, after 140 seconds from the start of the evacuation, it appeared that the bottleneck section gradually eased as all the individuals in the corridor successfully completed their evacuation. In Scenario 2, there was a congestion issue at the section and stairs entrance in the corridor (around R_{5-4}) This bottleneck seemed to be more pronounced compared to the one in Scenario 1, considering the time zone. Nevertheless, as the evacuation progressed, the congestion in the corridors lessened, and the flow of people gradually improved as the agents completed the evacuation within 140 seconds.

Figure 10 portrays the population density at the measuring point in Zone C for both cases. The population density in the left and right hallway (R5-2, R5-4) was 2.9~3.4 per/m^2 and 2.8~3.3 per/m^2 in Case 1 and Case 2, respectively, indicating that the population density decreased by 3.5 % in Case 2 compared to Case 1, and the reduction rate was very small. This is due to the lack of smooth agent flow within the stairs, which can be attributed to the narrow widths of the stairs. Additionally, there was a constant congestion of people in the hallway. During the ongoing evacuation, the population density in the measuring area gradually decreased. However, there was a noticeable disparity between Case 1 and Case 2 in the reduction process at point R_{5-2}. During Case 1, there was a gradual decline in population density starting 40 seconds into the evacuation. In contrast, Case 2 demonstrates a significant decline in density from 40 seconds to 80 seconds after the commencement of the evacuation.

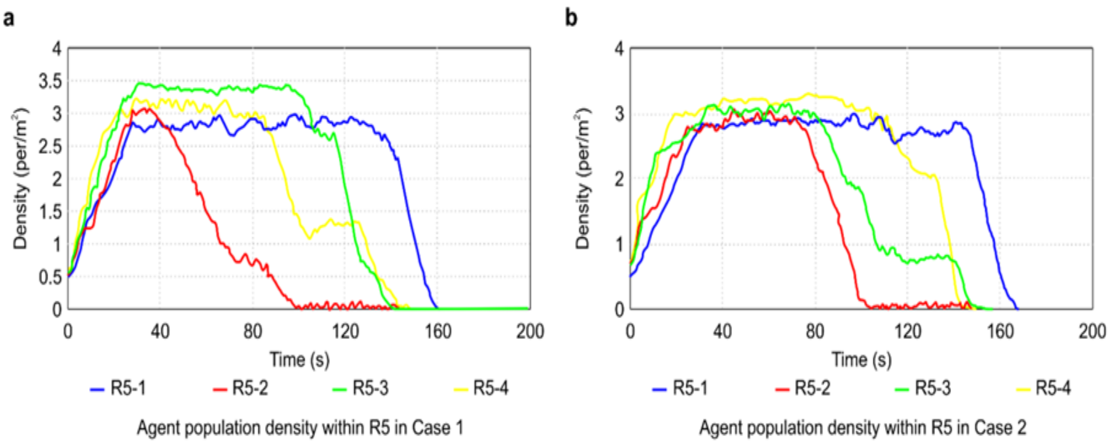

Figure 10. Population Density in Corridors for Zone C for (a) Case 1 and (b) Case 2.

Agents utilising the left hallway in Case 1 promptly proceed to Zone $R_{5\text{-}2}$ and navigate through the corridor without any additional personnel entering. However, in Case 2, despite the initial congestion in the left hallway, more agents flowed into the spot as they passed through the hallway at the beginning of evacuation. Consequently, the approach to reducing population density varied in the two scenarios. Table 4 displays the time it took for agents to complete their evacuation in the corridors and stairs of Zone C. In comparison to Case 1, the evacuation completion time in the hallway exhibited a rate of change ranging from -1.4 to 2.5% in Case 2, and a 1.0% change in the stairs. However, in Zone C, the evacuation completion time in the stairs and corridor remained relatively stable despite the installation of the sale stand. Upon examining the evacuation characteristics in Zone C, it was found that when the widths of the central part (R5-3) and stairs of the corridors connected to the stair entrance were narrow, smooth flow in the stairs and corridors was hindered in both cases. In Case 1, there was a congestion point at R5-3, while in Case 2, it occurred at R5-4.

Table 4

Agent Evacuation Completion Time in Corridors and Stairs for Zone C for Both Cases.

	Category	R5-1	R5-2	R5-3	R5-4	Stair	Category	Stair 9
Corridor	Case 1 (s)	162	98	147	145		Case 1 (s)	198
	Case 2 (s)	166	98	146	143		Case 2 (s)	201
	Rate of change (%)	▲2.5	-	▼0.7	▼1.4		Rate of change	▲1.0

The section that experienced congestion expanded throughout the entire corridor. In Case 2, the congestion lasted longer because the corridor was narrower compared to Case 1, likely due to the presence of a sales stand. There was no notable variation in the population density between Case 1 and 2, however, a distinction was observed in the process of population density reduction at point R5-2. Ultimately, it seems that the difference in the time it took to complete the evacuation in the hallway and stairs was not statistically significant.

5.1. Discussion, Conclusion, and Implications

5.1. Discussion on the Results highlights

The empirical findings underscored the significance of sales stands and their correlation with fire evacuation time in sports complexes in Korea. The compiled results indicate that evacuation time has a significant impact on the movement of people. The wide area of the stairs, central part of the corridor, and sales stand also play a role in influencing population density. It was observed that a wider area leads to increased movement of people, but also increases the disruption caused by smoke and heat. However, higher levels of agents decrease the movement of people. In addition, the empirical findings suggest that a narrow central part of the corridors combined with a wide stand stairs area can serve as an effective strategy for swiftly evacuating densely populated halls. This configuration allows for wide dispersion without impeding the movement of people. Furthermore, it has been suggested that the most effective method for evacuating the population and containing the fire involves utilising a narrow corridor through central park and narrow sales stands. This approach aims to minimise disruption for the population and reduce the influx of external air.

5.2. Conclusion

This study investigated the impact of a stand that extends from the corridor of an indoor sports complex on the evacuation behaviour of individuals. The study focused on an indoor sports complex located in Busan Metropolitan City. The study employed an experimental approach and focused on the indoor sports complexes being investigated. The data obtained from the experiment was analysed to determine the most effective options for fire evacuation. The results showed that a narrow width of the sales stand and the corridor of the central park of the sports complexes would ensure optimal distribution of agents in the smoke and help control the fire. Additionally, the presence of narrow stairs would minimise external entry.

5.3. Implications of the Study

The study contains valuable insights that can benefit practical field managers, authorities, and research scholars. This study has provided a unique contribution by demonstrating the important functioning of the fire evacuation process in sports complexes. It has also brought attention to the operation of the fire evacuation system in the sales stands that extend from the main corridor of the complexes to the exit stairs. The study has observed and shared the pattern of working of agents that track smoke and heat levels.

Furthermore, the study suggests a correlation between the width of corridors and stairs, emphasising their importance in the literature and practical applications. It concludes that wide stairs and narrow corridors are the most effective for efficiently evacuating densely populated areas and removing smoke from corridors. Additionally, these configurations facilitate the rapid response and containment of emergency fire situations. The study has provided valuable insights that can be utilised by public setting places management to enhance their system functioning and improve the safety of the public and existing population in their settings.

5.4. Limitations Observed

A limitation of this study is that it only investigated the change in agent evacuation characteristics caused by the reduction in corridor width due to protruding and installed sale stands. The effect of fire was not taken into consideration. This study did not provide any empirical evidence regarding the frequent changes in travel routes and evacuations made by agents in response to the direction of smoke and heat movement during fires. In addition, this study focused specifically on the indoor sports complexes of a single city, resulting in findings that are based on a limited sample size.

5.4. Future Research Directions

Other scholars can use the mentioned limitations for further investigation. This study did not assess the impact or severity of fire on the performance of the agents and the time needed for evacuation. Therefore, future studies should take this into account and examine the relationship between the level or impact of fire and evacuation time and agent performance. Additionally, it is important to note that the evacuation characteristics identified in this study may differ when considering the fire situation. Therefore, further research is necessary to complement the findings of this study. Finally, this study is limited by the data sample, which suggests an opportunity for future research to expand their investigations and include a wider range of settings.

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