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Promotion of Town Development Through Human Flow Simulation at Sports-Related Facilities

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Abstract. *In recent years, crowd congestion around large-scale sports facilities has emerged as a significant issue in urban safety and event management. This study evaluates the design and surrounding infrastructure of a planned new sports facility by simulating pedestrian flow using the Social Force Model and the S4 Simulation System. The facility, accommodating 15,000 people and located about 400 meters from the nearest train station, is expected to generate high post-event pedestrian volume. Nine simulation scenarios were tested by varying destination ratios and walking speeds based on age distribution. Results revealed that although average travel times remained similar across scenarios, significant differences in modal times and congestion points emerged depending on the agent distribution and routing assumptions. Key stagnation areas included the deck entrance and branching points within the facility. The study confirmed that while the basic design met safety requirements, inefficiencies in pedestrian flow—due to limited infrastructure and overly narrow walkways—hindered rapid dispersal. Based on the findings, the study recommends modifications to the infrastructure plan and plans for enhanced crowd guidance. The research findings underscore the importance of incorporating flow-based simulations into facility planning, contributing not only to visitor safety and satisfaction but also to data-driven urban development around large event venues.*

Keywords: *Pedestrian flow simulation, social force model, sports facility planning, urban infrastructure design, and post-event crowd management*

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Introduction

As of January 2024, plans are underway for the construction or renovation of 54 arenas and gymnasiums, and 42 stadiums and ballparks across Japan (JSA,2024). Large-scale events held in these facilities, such as sports games and concerts, result in crowds forming, as attendees move simultaneously to the nearest station after the event. This can lead to congestion at building exits and on narrow walkways, potentially causing pedestrian delays and reduced speed of movement, which may lead to accidents.

In September 2023, an event facility in Kanagawa, Japan, with a capacity of 20,000, experienced significant congestion after an event. Although the facility guides indicated an 11-minute walk to the station, complaints were later received that it took over two hours to get to the station (YS, 2023). Furthermore, the planned pedestrian deck connecting the facility to the station had not yet opened due to unforeseen ground changes and design errors leading to insufficient structural strength (Nx, 2024). Such situations negatively impact visitor satisfaction and can affect the ability of facilities to attract future events. Additionally, it can inconvenience pedestrians unrelated to the event, and local residents.

In July 2001, a crowd crush at a fireworks event in Hyogo, Japan, happened on a deck where flows of people heading to and from the venue converged. This tragic incident resulted in 11 deaths and 247 injuries (ACH,2002).

Accidents caused by crowds are occurring not only in Japan but all over the world, and I believe that resolving this issue is an urgent task. (TR, 2024; GNM, 2005) To ensure visitor satisfaction and prevent accidents at facilities hosting large-scale events, it is crucial to implement effective crowd management strategies. This can include designing facilities with crowd flow in mind from the planning stages, and managing visitors as efficiently as possible. Moreover, involving both public and private sectors in urban development is necessary to ensure proper infrastructure, such as maintaining pedestrian routes, in the surrounding areas.

Human Flow Simulation and Facility Design

To ensure visitor satisfaction and prevent accidents at large event venues, it is necessary to implement proper crowd management during events by designing facilities based on anticipated human flow during the planning stages. This would enable more efficient handling of visitors. Moreover, integrated urban planning, including pedestrian routes and surrounding infrastructure, should be pursued with public and private sector collaboration. One approach to designing facilities based on human flow is simulation, and numerous studies have been conducted on this subject.

To simulate pedestrian movement inside buildings, Okazaki (1979) used a magnetic model and equations of motion, including the choice of evacuation routes and changes in the amount of smoke present. He also simulated crowds walking in congested areas, reproducing their avoidance of other pedestrians and columns. Kimura et al. (2009) used a multi-agent model in a real coordinate system to simulate how pedestrians avoided collisions. However, these models are limited to abstract spaces, and there is a lack of knowledge regarding simulations of complex route selection inside real buildings.

Concerning simulations of movement within real buildings, Sato et al. (2009) highlighted the importance of guidance during emergencies by simulating the concentration of evacuees at specific exits and the resulting congestion in a station. Kojima & Katsuno (2016) simulated an evacuation in a school, examining congestion points and evacuation times to evaluate the evacuation methods and routes. Minegishi & Takeichi (2015) constructed models of evacuation that considered the convergence of human flows to and from unique audience seats and vertical or horizontal passages in stadiums and theaters. Furthermore, Takayanagi et al. (2016) used a digital environment to reproduce crowd behavior at a large terminal station and assessed gate placement and line planning aimed at reducing congestion. These studies used realistic models to analyze problems arising during evacuations, and suggested potential improvements. However, their findings are limited to simulations within specific buildings during emergencies, and there are few simulations of human flows across multiple buildings during normal times.

To simulate human flows after large events in stadiums, Minegishi (2023) recorded the travel time and speed from the stadium to public transportation after sports events to assess crowd behavior and identify challenges during disasters. Takahashi et al. (2024) installed fixed-point cameras between a stadium and the nearest station, to measure the number of passersby, walking speed, and crowd density. They set parameters for the simulation, and examined crowd control, clarifying the permissible congestion threshold for bottlenecks. These models provide useful insights, but they are limited to completed buildings, and their measures rely on temporary fences and guides.

Although some existing studies simulate human flow, many are limited to abstract spaces. Simulations within real buildings primarily focus on emergencies, while those considering normal times often pertain to completed buildings. There is a lack of studies that apply simulation results to actual facility design.

This study conducted simulations of human flows from event venues to the nearest stations after the event. The simulations used the Social Force Model for newly planned sports facilities, and were based on current architectural plans. The validity of the current architectural plans and surrounding infrastructure will be verified based on the simulation results.

This research enables sports facilities and surrounding infrastructure to be designed based on simulations, ensuring the safety and satisfaction of visitors while contributing to the promotion of comfortable urban development. These methods can potentially be applied to identify issues and reflect solutions in the design of planned new or renovated arenas and stadiums and their surrounding infrastructures.

This study developed a pedestrian simulation model suitable for application during the design phase of a sports facility to reproduce post-event pedestrian behavior. Potential flow-related issues were identified, and data-driven insights were provided for improving the design of the facility and its surrounding infrastructure.

Research Methodology

Overview of the Target Facility

The sports facility is located approximately 400 meters from the nearest train station and is planned to be connected to the station via a deck. The facility has a maximum capacity of around 15,000 people. It will serve as the home arena for a professional basketball team and will host a variety of events, including concerts, sports events, and exhibitions. This study focused on simulating pedestrian flow from the facility exits to the station, centering on the deck.

Software Used

This study used the S4 Simulation System provided by NTT DATA Mathematical Systems Inc. to conduct pedestrian flow simulations using the Social Force Model.

The Social Force Model consists of spaces where agents can and cannot move. Each agent is represented as a mass point and is considered to be a particle moving in a plane. Each agent has a destination but is influenced by interactions with other pedestrians and obstacles, as described by the following motion equation for a pedestrian i with mass mi :

$$m_i \frac{d\vec{v_i}}{dt} = m_i \frac{v_{0i}\vec{e_i}(t) - \vec{v_i}}{\tau_i} + \sum_{j(\neq i)} \vec{f_{ij}} + \sum_W \vec{f_{iW}} \quad (1)$$

$\vec{e_i}$: vector towards destination

$\vec{v_i}(t)$: current speed

$\vec{f_{iW}}$: external force exerted on pedestrian i from obstacle W

v_{0i} : optimal speed for pedestrians

$\vec{f_{ij}}$: external force applied from pedestrian j to pedestrian i

This study simulates event attendees leaving the facility, with each agent representing one attendee.

Common Conditions

Agents were generated at the facility exits and were set to move towards one of three destinations: the nearest station gate, another station via a second-floor escalator, or another station and other destinations via the first-floor plaza. They disappeared upon reaching their destination. It was assumed that agents would choose the shortest path to their destination, even if it meant taking different routes to the same endpoint. The simulation used a fixed number of agents (representing the deck users) and tested three scenarios each for destination ratios and optimal walking speeds, resulting in a total of nine scenarios. The facility owner expects all attendees to be processed within 30 minutes.

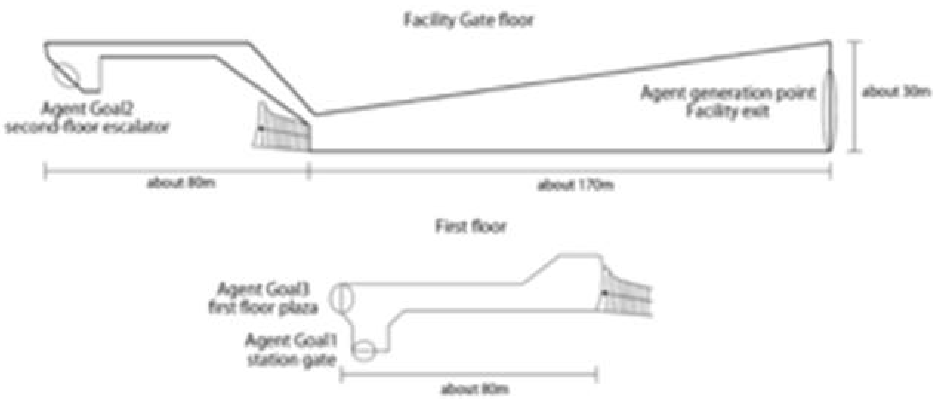

Figure 1.
Simplified Diagram of the Model

Scenarios

Number of Agents Using the Deck

The maximum capacity of the facility is approximately 15,000 people. It was predicted that approximately 12,000 would head towards the train station, and the remaining approximately 3,000 would stay in the accommodation and use the commercial and hot spring facilities attached to the arena after the event. Furthermore, of the 12,000 people heading towards the train station, the environmental assessment predicted that approximately 73% (8,760 people) would use the deck. Based on the results of interviews with similar facilities, it was estimated that visitors could complete their exit from the target facility in 30 minutes, with the number of people exiting at peak times being 4,370 people/15 minutes.

For this study, a simulation was performed with the number of agents set to the number of people exiting during peak times as described above.

Agent Destination Ratios

The assumed ratios of deck users heading to the nearest station gate, another station via the second-floor escalator, or another station and other destinations via the first-floor plaza were 30:37:33.

The study tested the following scenarios:

a. 30:37:33
b. 40:30:30
c. 20:40:40

Conditions b and c are merely assumptions in order to compare and verify the cases in which flow is concentrated or dispersed onto the pedestrian-only deck.

Optimal Walking Speed

Walking speeds vary by age, as shown in Table 1

Considering that the facility will primarily host events targeting young people and families, the following age distribution scenarios were tested:

d. 20s:30s:others= 2:2:1
e. Under 10:30s:others= 2:2:1
f. Completely random

In scenario e, agents under age 10 were assigned adult 'companions' whose walking speed was synchronized to that of the child. For “Others,” ages ages were assigned randomly, and the corresponding optimal walking speed applied accordingly.

Number of Simulation Runs and Calibration Strategy

For each scenario, the number of simulation runs was set to three. This limitation was due to the current performance constraints of the S4 Simulation System. While the system is typically optimized for simulations involving approximately 500 agents, the present study required simulating a significantly larger crowd to reflect the expected conditions at the facility. Therefore, it was necessary to reduce the number of executions to maintain computational feasibility.

Regarding the calibration of the Social Force Model, two possible approaches are considered:

i) Improved Computational Capacity:

If future upgrades to the S4 system enable simultaneous simulation of a higher number of agents suitable for this facility, the model could be run approximately 30 times per scenario. This would allow for statistically meaningful evaluations of average behavior and distributional characteristics.

ii) Post-Construction Observation and Calibration:

Once the facility is completed, empirical observations such as video footage, dwell times, and pedestrian speed data can be collected during actual post-event conditions. These observational results will be used to quantitatively assess discrepancies between the simulation and real-world outcomes. Based on this comparison, parameter calibration will be conducted to refine the model. The calibrated model can then be tested for its ability to reproduce other types of events or alternative exit layouts, thereby confirming its generalizability and applicability to real-world situations.

Table 1.
Agent walking speed

Age group	Walking speed (m/min)
Under 10	59
10s	77
20s	80
30s	80
40s	78
50s	70
60s	64
70s	55

In this experiment, we conducted nine scenarios: a-d, a-e, a-f, b-d, b-e, b-f, c-d, c-e, and c-f. We measured the agent IDs, generation times, extinction times, and dwell times during these scenarios.

Due to the number of sample limitations, statistical tests were not conducted; however, visual comparisons of histograms and descriptive metrics suggest the possibility of congestion.

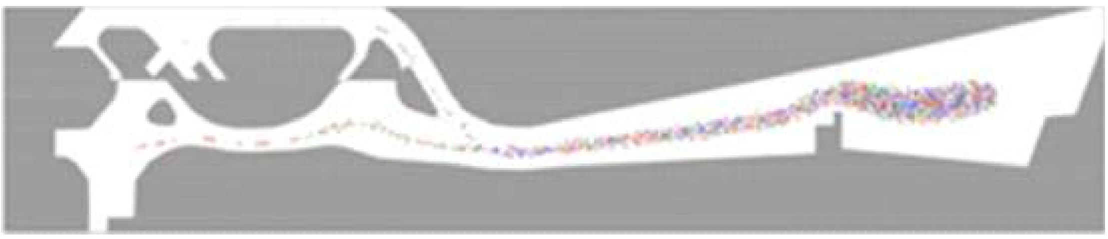

Figure 2.
Simulation Run Screen

Scenario a-d(base Scenario)
This is the currently predicted base scenario. The minimum travel time to the destination was approximately 3 minutes, the maximum was about 35 minutes, with an average of around 17 minutes, and the mode was approximately 24 minutes.

The approximately 7-minute gap between the mean and the mode suggests that congestion and stagnation may occur during specific time intervals. The histogram distribution exhibits right skewness, indicating the presence of local bottlenecks on the deck and within the facility.

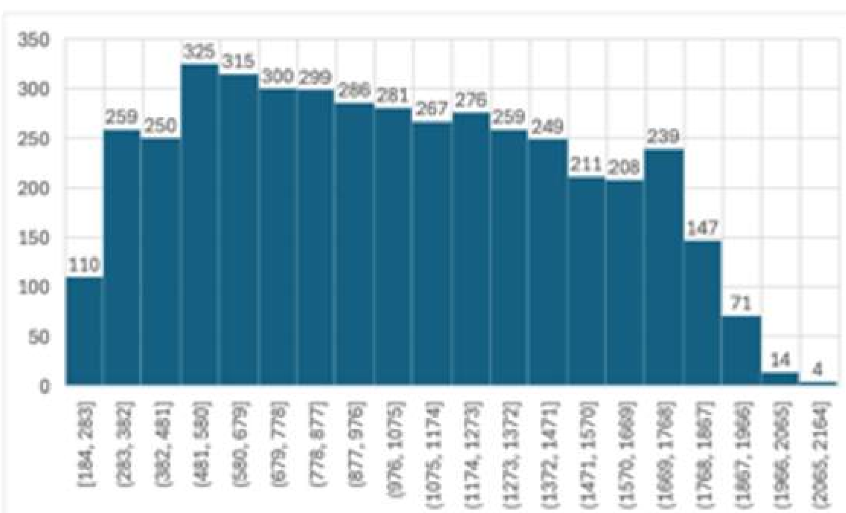

Figure 3.
Histogram on dwell time (s) Scenario a-d

Scenario a-e

The minimum travel time to the destination was approximately 3 minutes, the maximum was about 36 minutes, and the average was around 18 minutes, all of which were almost identical to those in the baseline scenario a-d. However, in this scenario, the mode was around 26.5 minutes, showing a difference of about 1.5 minutes compared to the baseline scenario. The further shift of the mode to a later time compared to a-d indicates a prolonged or intensified congestion peak. This is likely due to the lower walking speed assumptions based on families with young children in Scenario e, as opposed to the faster walking speeds of individuals in their 20s and 30s in Scenario d.

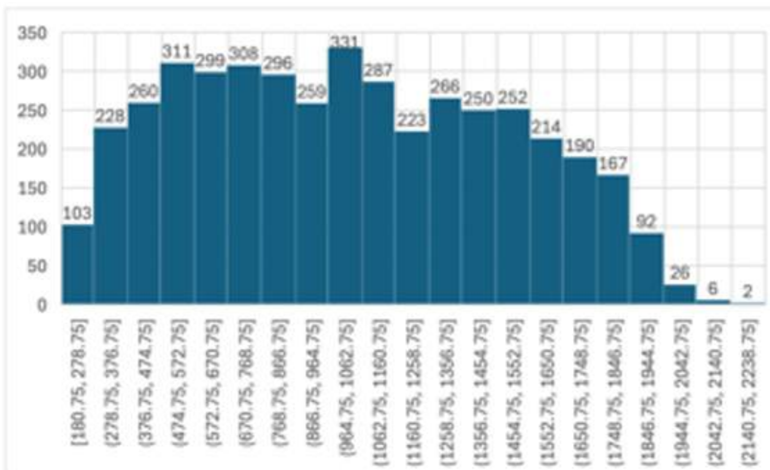

Figure 4.
Histogram on dwell time (s) Scenario a-e

Scenario a-f

The minimum travel time to the destination was approximately 3 minutes, the maximum was about 36 minutes, and the average was around 17 minutes, all of which were almost identical to those in the baseline scenario a-d. However, the mode was about 13 minutes, which is roughly half of the value observed in scenario a-d. The significantly shorter mode implies that many agents were able to pass through quickly. However, the unchanged maximum travel time suggests that this alleviation did not extend across the entire population. It is possible that the population bifurcated into an early-exiting group and a trailing group who experienced stagnation.

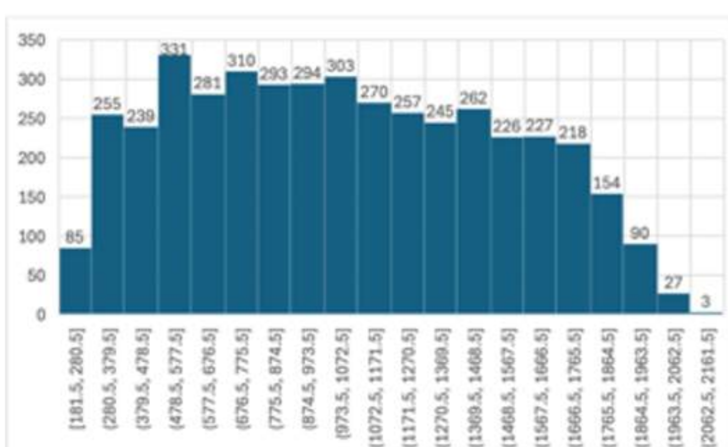

Figure 5.
Histogram on dwell time (s) Scenario a-f

Scenario b-d

The minimum travel time to the destination was approximately 3 minutes, the maximum was about 36 minutes, and the average was around 17 minutes, all of which were almost identical to those in the baseline scenario a-d. However, the mode was significantly shorter, at approximately 14 minutes, compared to the values observed in the baseline scenario a-d. The mode was shortened by more than 10 minutes, indicating a temporary easing of congestion or the effectiveness of alternative routes. This may result from the higher proportion of agents heading to the nearest station in Scenario b. However, the unchanged maximum time implies that structural congestion remained in some areas.

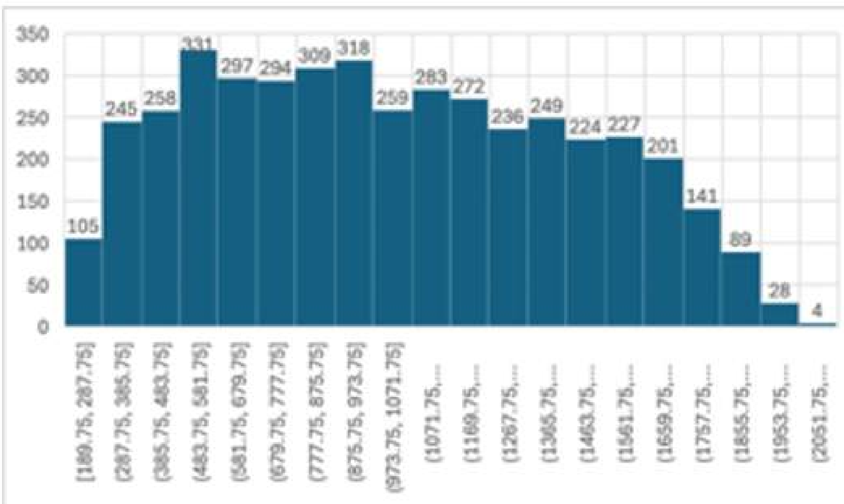

Figure 6.
Histogram on dwell time (s) Scenario b-d

Scenario b-e

The minimum travel time to the destination was approximately 3 minutes, the maximum was about 36 minutes, and the average was around 18 minutes, all of which were almost identical to those in the baseline scenario a-d. However, the mode was significantly shorter, at approximately 14 minutes, compared to the values observed in the baseline scenario a-d, and was almost the same as those in scenario b-d. The continued downward trend in the mode suggests that building in the early passage of agents was generally successful. However, since this scenario assumes a high number of families with young children heading to the nearest station, slower walking speeds likely contributed to suppressing stagnation. The rise in the mean travel time suggests that later agents were still affected by congestion, indicating that the improvement was only partial.

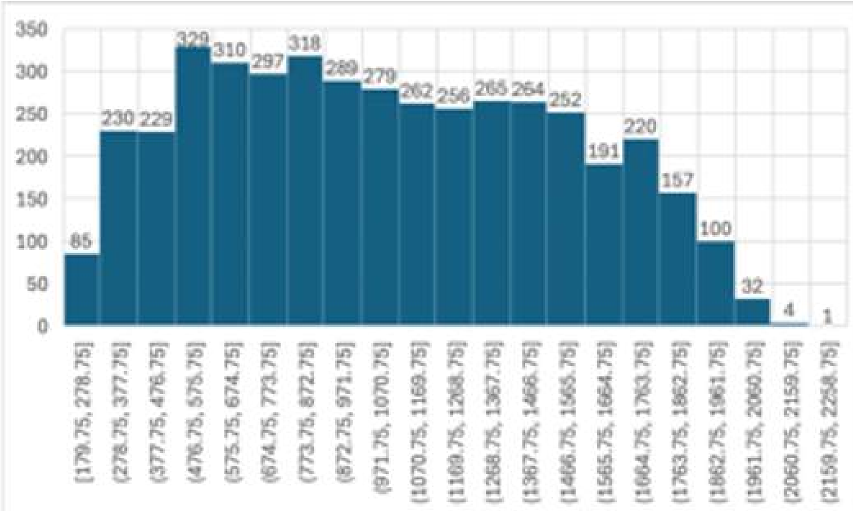

Figure 7.
Histogram on dwell time (s) Scenario b-e

Scenario b-f
The minimum travel time to the destination was approximately 3 minutes, the maximum was about 36 minutes, and the average was around 17 minutes, all of which were almost identical to those in the baseline scenarios a-d. However, the mode was approximately 11 minutes, which is about half of the value observed in the baseline scenarios a-d and shorter compared to the values in scenarios b-d and b-e. This is the shortest mode among all scenarios, and suggests that the rerouting design worked well for a certain portion of the population. This outcome is presumably due to the higher share of agents using the nearest station in Scenario b. However, the lack of improvement in the maximum travel time indicates that peak-time congestion remained unresolved in some sections, possibly due to structural constraints.

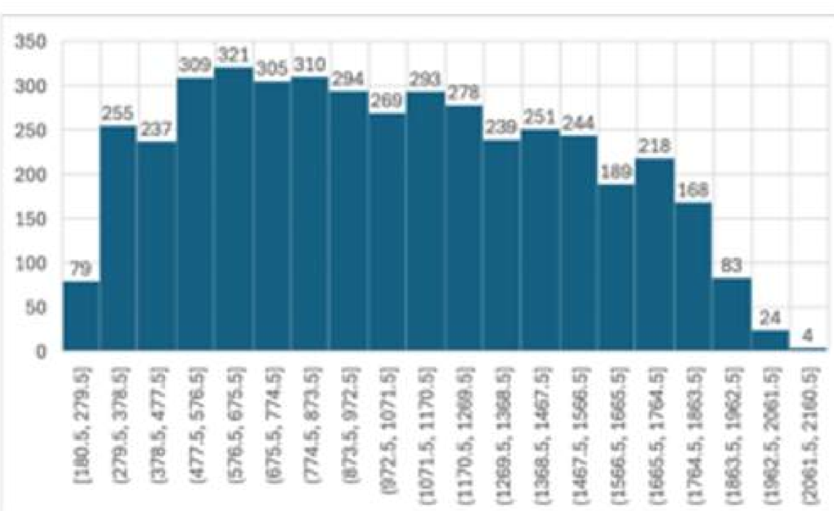

Figure 8.
Histogram on dwell time (s) Scenario b-f

Scenario c-d

The minimum travel time to the destination was approximately 3 minutes, the maximum was about 35 minutes, and the average was around 17 minutes, all of which were almost identical to those in the baseline scenario a-d. However, the mode was significantly shorter, at approximately 13 minutes, compared to the values observed in the baseline scenario a-d. The shorter mode suggests that congestion was alleviated during certain time intervals. Nevertheless, the unchanged average and maximum times indicate that congestion was still concentrated during specific periods, suggesting the need for time-based dispersion strategies.

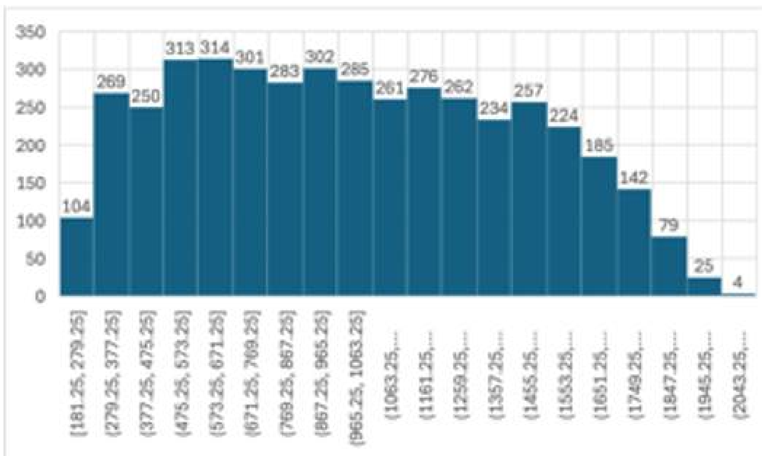

Figure 9.
Histogram on dwell time (s) Scenario c-d

Scenario c-e

The minimum travel time to the destination was approximately 3 minutes, the maximum was about 37 minutes, and the average was around 17 minutes, all of which were almost identical to those in the baseline scenarios a-d. However, the mode was approximately 8 minutes, which is less than half of the value observed in the baseline scenarios a-d. It was also about 5 minutes shorter than in scenarios c-d, making it the shortest among all scenarios. The extremely short mode indicates a route that functioned particularly efficiently. However, the significant discrepancy with the maximum time—the longest among all the scenarios—suggests an increase in travel time due to route selection. This highlights the need for better guidance strategies to evenly distribute pedestrian flows.

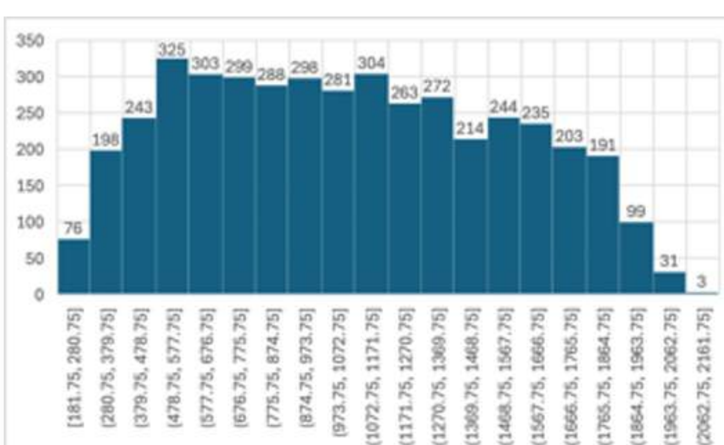

Figure 10.
Histogram on dwell time (s) Scenario c-e

Scenario c-f

The minimum travel time to the destination was approximately 3 minutes, the maximum was about 35 minutes, and the average was around 17 minutes, all of which were almost identical to those in the baseline scenario a-d. However, the mode was significantly shorter, at approximately 14 minutes, compared to the values observed in the baseline scenario a-d, and was similar to those in scenario c-d. Although the mode was reduced, the average and maximum travel times remained unchanged. This suggests that flow dispersion had a limited effect on peak congestion. Moving forward, dispersion strategies targeted at specific high-congestion time windows will be necessary.

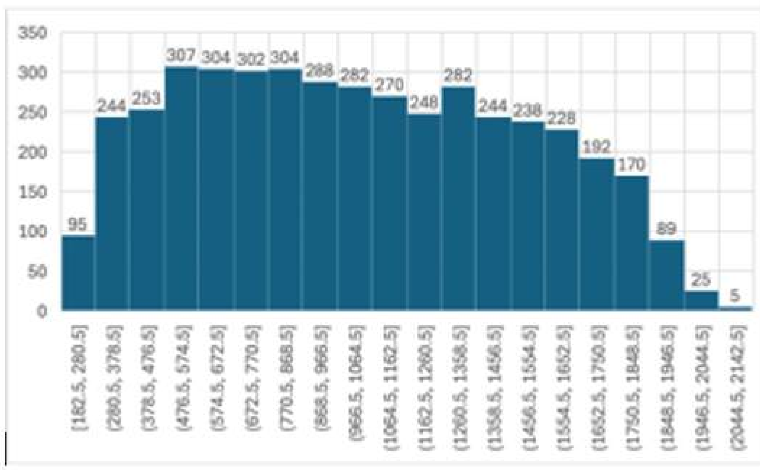

Figure 11.
Histogram on dwell time (s) Scenario c-f

Table 2.
Table Of Figures For Retention By Scenario

Scenario	Min	Max	Mean	Mode	Median	Standard deviation	Mean-Mode	Mean-Median	CV (Standard deviation /mean)
a-d	184.00	2126.25	1019.05	1430.25	992.38	461.19	-411.2	26.67	0.453
a-e	180.75	2148.00	1051.96	1585.00	1036.25	462.08	-533.04	15.71	0.439
a-f	181.50	2152.00	1033.40	774.00	1001.88	463.58	259.4	31.52	0.449
b-d	189.75	2147.25	1020.50	818.00	983.50	458.49	202.5	37	0.449
b-e	179.95	2173.00	1073.52	843.00	1004.00	463.59	230.52	69.52	0.432
b-f	180.50	2143.00	1029.34	643.00	1002.25	460.68	386.34	27.09	0.448
c-d	181.25	2136.50	1009.49	758.50	981.00	456.32	250.99	28.49	0.452
c-e	186.00	2195.75	1027.14	485.50	1001.25	458.36	541.64	25.89	0.446
c-f	182.50	2106.00	1024.54	817.00	994.13	459.63	207.54	30.41	0.449

Three statistical indicators were employed to quantitatively evaluate congestion patterns, polarization tendencies, and stagnation structures across all scenarios:

- Mean–Mode difference: Indicates the skewness of the distribution, particularly the lag between the average and peak occurrence.
- Mean–Median difference: Reflects the influence of outliers or extreme values.
- Coefficient of variation (CV): Represents the relative variability (Standard Deviation ÷ Mean).

Areas Prone to Crowd Congestion

The areas prone to crowd congestion are as follows:

Point ①: Between the venue and the deck

Point ②: Near the grand staircase

Point ③: The passageway at the bottom of the stairs

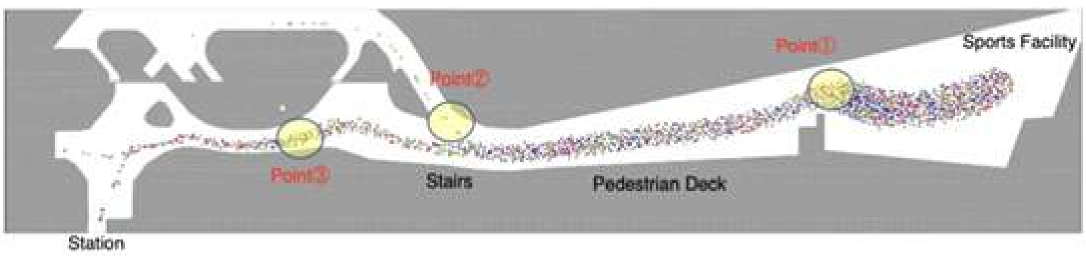

Figure 12.
Simulation run screen - Stagnation points

Comparisons Between Scenarios

When comparing the scenarios, significant differences were observed in the mode of travel time to the destination, while there were no clear differences in the minimum, maximum, and average travel times.

The mode was lower in Scenario B and Scenario C compared to Scenario A. This may be due to the number of locations where agents tended to gather. In Scenario A, the flow of people descending the stairs and heading toward the first floor intersects at the branching point to the second-floor escalator (Point ②), and agents may also be slowing down as a result of crowding in the first-floor plaza (Point ③).

In Scenario B, although the number of agents passing through the first-floor plaza increases due to the higher number of agents descending the stairs to the first floor, there is less crossing of agents at the branching point (Point ②), which reduces congestion and potentially leads to a lower figure of mode.

In Scenario C, the reduction in the number of agents passing through the first-floor plaza (Point ③) and the resulting decrease in congestion might explain the lower mode.

The findings show that the lack of clear differences between the minimum, maximum, and average travel times could be attributed to two factors: First is the agents. The walking speed of the agents. The walking speed was determined by a normal distribution, with the average speed based on the optimal walking speed corresponding to the agent's age, and the variance set at 0.01 times the optimal speed. However, the differences in speed due to age were minimal in the simulation, likely resulting in only a minor impact on travel time.

Second is the destination setting. The objective of this experiment was to define the ratio of destinations and observe whether changes in route congestion affected clearance within a specified time. However, since the number of agents was relatively high for the specified routes, the agents in the scenarios might have already been in a low fluidity state, and adjusting the distribution of destinations may not have resulted in noticeable differences.

The Mean–Mode difference was positive or large in all scenarios, suggesting right-skewed distributions indicating the presence of delayed agents who remained in the system longer than average. In particular, Scenario c–e showed a large positive value of +541 seconds, implying severe congestion during peak times that caused significant delays for those following. Conversely, scenarios a–e and a–d showed negative values of -533 seconds and -411 seconds, respectively, implying that many agents passed through earlier than the mean, and that the overall passage time was skewed toward the faster exits.

Regarding the Mean–Median difference, values of approximately +30 to +70 seconds were observed across all scenarios. This suggests that a small number of agents with prolonged dwell times inflated the average travel time. Scenario b–e showed a notably large difference, indicating that long-duration agents had a strong upward influence on the mean.

The Coefficient of Variation (CV) exceeded 0.43 in all scenarios, reflecting a substantial degree of disparity in travel times among agents. Scenarios a–d and c–d exhibited particularly high CVs, implying a pronounced bimodal structure where one group passed through quickly while another experienced significant stagnation.

By integrating these statistical indicators, it becomes possible to move beyond simple averages and gain a more three-dimensional understanding of skewness, dispersion, and congestion structure in each scenario. In future work, these metrics can be used to quantitatively identify bottleneck areas and develop heatmap analyses based on dwell time thresholds, contributing to more refined proposals for facility and infrastructure improvements.

Results and Discussion

Limitations in Previous Research and the Significance of This Study

Previous research has been limited to scenarios that make assumptions about movement within specific buildings during emergencies. This highlights the importance of setting parameters based on actual data measured in real buildings to improve simulation accuracy. For example, the study by Takahashi et al. (2024) analyzed pedestrian flows around an actual stadium the Tokyo Dome following the conclusion of baseball games. Their work involved calibrating simulation parameters based on empirical data such as walking speeds and congestion patterns. As a result, they succeeded in improving the model's accuracy. Notably, their research clarified the acceptable threshold of congestion at bottlenecks based on observed flow rates and demonstrated that smoothing peak inflows into bottleneck areas can effectively alleviate crowding.

The methodological approach and insights from their study are highly relevant and transferable to the present research. Although the sports-related facility targeted in this study is only scheduled to open in or after October 2030 and no observational data are currently available, future developments will allow for the integration of empirical validation.

Once the facility is completed, post-event pedestrian data such as video footage, dwell times, and walking speed variations can be collected and compared quantitatively with the simulation outputs created in this study. This will enable the calibration of model parameters to align with real-world conditions, thereby allowing for verification of the model's generalizability and practical applicability.

By leveraging the findings of Takahashi et al. (2024), it will be possible to determine acceptable levels of crowding at bottlenecks in the planned facility and implement feasible and evidence-based congestion mitigation strategies.

By predicting pedestrian flow during normal times across multiple buildings using the Social Force Model for a new sports-related facility, this study makes it possible to identify design and infrastructure challenges in advance, preventing accidents.

Confirmation of the Base Scenario

In the base scenarios a-d, no congestion leading to a stack through the pedestrian deck to the nearest station occurred, confirming that there are no design issues. However, the pedestrian flow set in the environmental assessment did not meet the service level A (~27 people per meter per minute), resulting in longer-than-expected passage times.

This is likely due to the design calculating pedestrian flow without considering agent directionality (e.g., stopping or moving backward) and the developer's intention to secure as much high-revenue tenant space as possible, leading to the minimum amount of space being allowed for passageways.

Verification of Scenarios and Results

Additionally, to verify the deck's load-bearing capacity, simulations were conducted for nine scenarios. The results were almost the same as those of the base scenario. This was because some congestion had already occurred in the base scenario, making it unaffected by the conditional differences applied in scenarios 2 and 3.

The need for Infrastructure Plan Modifications and Customer Guidance Measures

If the simulation reveals a high likelihood of pedestrian stagnation on the deck, there is potential to revise part of the foundational infrastructure plan, such as widening the pedestrian deck. However, in cases where revisions to the physical design are limited due to constraints such as local residents opposition to land acquisition alternative strategies may be implemented. These include enforcing staggered or regulated exit procedures, deploying additional crowd control staff, and installing dynamic signage to guide pedestrian flow.

Stakeholder Benefits of Integration with Urban Planning

Planned stadiums and arenas are typically approved for development under the condition that they align with broader urban planning policies established by local governments. These include providing enhancements to surrounding infrastructure such as roads and parks, which facilitate effective land utilization and supports the issuance of development permits. Local authorities are required to evaluate projected peak traffic volumes associated with such large-scale developments before granting approval. However, there have been numerous cases where unforeseen crowd formations beyond what was anticipated during the planning phase have led to incidents and operational challenges. Therefore, the use of human-behavior-based simulations during the planning stage allows for the early identification of potential risks related to facility design and surrounding infrastructure. This proactive approach can help prevent accidents and support the realization of more effective and resilient urban planning from the perspective of local governments. Furthermore, this contributes to delivering safe and comfortable services not only to stadium and arena visitors, but also to a wide range of local stakeholders including residents, landowners, commercial operators, and transportation service providers ensuring shared benefits across the surrounding community.

Toward Internationally Applicable and Practically Robust Facility Design

The planning of the sports-related facility targeted in this study is currently undergoing Environmental Impact Assessment (EIA). This entails investigation, forecasting, and evaluation of the potential environmental impact associated with large-scale development projects. With reference to the EIA results, feedback is collected from residents, experts, and governmental authorities, and appropriate environmental protection measures are subsequently implemented. The current facility design is

therefore grounded in a set of objective evaluation criteria established through this formal procedure. However, considering recent advances in AI- and IoT-based crowd management technologies, there is potential to further enhance the facility's design by incorporating relevant international design standards. These include:
NFPA 101 (Life Safety Code): A widely adopted standard for life safety in buildings, covering evacuation design and occupant load criteria;
EN 13200 (CEN Standard): European guidelines for the design and management of spectator facilities, particularly in the context of sports venues;
ISO 22320:2018: International standard for emergency management, including crowd safety and coordination during large-scale events.

By integrating such international standards into the design process alongside domestic regulatory frameworks it may be possible to enhance not only the safety and efficiency of the facility but also its visual quality, operational resilience, and adaptability to international best practices. This integrated approach would contribute to a facility design that is both functionally robust and globally applicable, offering long-term value for operators, users, and the surrounding community.

Study Contributions
This study verified the validity of using simulations in the design of sports-related facilities and their surrounding infrastructure. Simulations can increase the safety and satisfaction of visitors to such facilities, and contribute to the promotion of a comfortable urban environment.

Conclusion

This study developed a simulation-based design methodology that allows urban planners and facility managers to proactively evaluate and mitigate pedestrian congestion risks in the early stages of sports facility development. This study utilized the Social Force Model to simulate pedestrian flow, thereby verifying the validity of using simulations in the design of facilities and surrounding infrastructure. The results suggested that visitor safety and efficiency were ensured, which contributes to the urban planning literature. In the future, it is expected that applying similar methods to newly constructed or renovated arenas, stadiums, and other facilities will help identify issues and incorporate them into facility design and infrastructure planning, to prevent the occurrence of accidents and other incidents.

Declaration

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All authors contributed equally as the main contributors of this paper. All authors read and approved the final paper.
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Competing Interest
The authors declare that they have no conflicts of interest to report regarding the present study.

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