

SIMULATION OF EMERGENCY EVACUATION IN AIRPORT TERMINAL DEPARTURE HALLS

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Abstract

To identify bottlenecks and propose optimization strategies for emergency evacuation at airport terminals, this study developed a pedestrian evacuation model using AnyLogic simulation software, with Zhengzhou Xinzheng Airport Terminal T2 as a case study. Pedestrian density distribution and evacuation time dynamics were analysed. Issues such as initial exit crowding and imbalanced passage configuration were revealed. Average evacuation time and median changes before and after optimization were calculated. A multilevel evacuation strategy centred on diversion in key areas and passage resource optimization was proposed. Results show that the initial average evacuation times for Scenarios 1, 2, and 3 are 258.47 s, 223.63 s, and 235.33 s, respectively. Through the application of diversion guidance and passage optimization, evacuation efficiency is improved by approximately 9.7%, 2.3%, and 14.4%, respectively, with the integrated scheme combining multi-area diversion and passage management proving most effective. The findings provide a scientific basis and methodological support for emergency evacuation planning and spatial layout optimization in airport terminals.

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Key Words: Airport, Terminal, Emergency Evacuation, Simulation Optimization

1. INTRODUCTION

As the core hub of modern integrated transportation networks, airport terminals not only serve the essential function of concentrated passenger throughput but also act as critical nodes for aviation logistics circulation. The complex spatial structures, densely arranged functional zones, high instantaneous passenger volumes, and strong personnel mobility that are characteristics of terminal buildings determine that emergency evacuation capability has become a fundamental element in ensuring airport operational safety [1, 2]. In the event of emergencies, such as fires or terrorist threats, failure to complete personnel evacuation within the safe time threshold may directly lead to significant casualties, property losses, and public safety crises. Therefore, the scientific validity and effectiveness of terminal emergency evacuation systems are of paramount importance.

The complexity of emergency evacuation in airport terminals is reflected across multiple dimensions. First, passengers are prone to stress-induced behaviour, such as panic and blind following, under emergency conditions; such behaviour significantly differs from normal behaviour patterns and increases the difficulty of evacuation organization [3]. Second, the evacuation process exhibits dynamic evolution characteristics, where high passenger volume interacts with diverse internal facilities, resulting in complex and variable pedestrian flow trajectories [4]. Third, evacuation efficiency is influenced by the coupling of multiple factors, including individual characteristics (e.g., passenger age and physical condition), organizational elements (e.g., evacuation guidance methods and signage system design), and hardware conditions (e.g., terminal spatial layout and safety exit configurations) [5, 6]. This complexity collectively indicates that emergency evacuation issues cannot be addressed through empirical judgment alone, necessitating systematic evaluation based on scientific methodologies. This study focuses on the departure hall of airport terminals as the study subject. It systematically

analyses the evolution patterns of terminal emergencies, spatial characteristics of departure halls, and the mechanisms of pedestrian emergency behaviour. Then, it employs AnyLogic simulation software to develop a realistic evacuation model. This model simulates personnel flow processes under different scenarios to identify evacuation bottlenecks and risk nodes.

2. STATE OF THE ART

Previous research has focused on emergency evacuation at airport terminals, primarily examining risk assessment, evacuation efficiency, and strategy optimization. In the field of airport evacuation risk assessment, prior work has developed agent-based risk assessment models, integrating gas dispersion and pedestrian movement data to optimize evacuation procedures. For evacuation efficiency and strategy optimization, multidimensional approaches that encompass algorithm improvements, behavioural analysis, facility optimization, and scenario design have been adopted to enhance evacuation efficiency and safety significantly.

With regard to airport evacuation risk assessment, existing studies have emphasized addressing emergency escape challenges, with focus on emergency evacuation strategies and the application of multidisciplinary models to optimize evacuation procedures and risk assessment. Luan et al. [7] proposed that constructing an agent-based risk assessment model and its corresponding algorithm, while integrating gas dispersion and pedestrian movement data into emergency response systems, enables rapid assessment of individual average exposure risk. They further indicated that in the event of a gas attack at an airport terminal, ventilation should be halted immediately and evacuation initiated promptly. For areas that implement shelter-in-place strategies, ventilation modes and sheltering duration should be determined based on indoor and outdoor gas concentrations. In high-population-density areas exposed to nerve agents, additional evacuation exits are required. Ma et al. [8] proposed establishing a resilience-based framework for large-scale passenger flow (e.g., sudden massive passenger flow) evacuation response, which can effectively reduce evacuation time under large-scale flight delay scenarios, significantly enhancing the disaster resilience of transportation systems. Guo et al. [9] applied an evacuation flow equilibrium method based on crowd evacuation dynamics theory by using the A-configuration cabin layout of a Boeing 737-800 as an example. By simulating three evacuation scenarios, they identified key factors that caused cabin evacuation congestion and proposed a strategy for minimizing evacuation time. Their study demonstrated that the balanced use of emergency exits can significantly shorten evacuation time and improve evacuation efficiency. Tang et al. [10] constructed a systematic simulation framework to identify worst-case scenarios in the crowded waiting halls of roll-on/roll-off passenger terminals. By simulating passenger flow and evacuation behaviour, they achieved a more precise and reliable assessment of passenger evacuation performance. However, existing studies have predominantly focused on model construction and theoretical deduction, lacking the detailed identification and dynamic assessment of evacuation bottlenecks in real, complex spatial environments. Insufficient validation and testing, particularly regarding multi-exit coordination and real-time channel resource allocation, limit the applicability of these models in actual emergency decision-making.

For terminal evacuation efficiency and strategy optimization, existing study centres on airport terminal emergency evacuation strategies, emphasizing multidimensional approaches, such as algorithm improvements, behavioural analysis, facility optimization, and scenario design, to enhance evacuation efficiency and ensure passenger safety. Zhu et al. [11] proposed that incorporating actual personnel distribution within terminals and improving the A* algorithm can significantly enhance evacuation efficiency, enabling terminals to complete passenger evacuation more rapidly during emergencies. Cheng and Chen [12] indicated that in terminal fire scenarios, the evacuation efficiency of individuals with group behaviour is lower

than that of those without, leading to prolonged evacuation times. This effect is particularly pronounced when the damage rate of guidance facilities reaches 90 %. Optimizing group ratios and pedestrian density can significantly improve efficiency. Their independent cascade model effectively demonstrated the effect of information dissemination on the evacuation process, providing reliable data support for airport emergency drills. Si et al. [13] used PyroSim software to simulate fire smoke dispersion at the Zhengzhou Air-Rail Intermodal Hub Station; they found that smoke exhaust system failure shortens safe egress time and severely affects personnel evacuation efficiency. Their conclusions provide important references for fire evacuation decision-making at hub stations. Qi et al. [14] considered the effect of nonadaptive crowd behaviour on terminal emergency evacuation efficiency. Their simulation results showed that such behaviour increases passenger evacuation time and expand conflict zones, revealing inadequacies in existing emergency evacuation plans. This finding necessitates the optimization of terminal layout design and on-site management strategies. Zhou et al. [15] proposed a real-time decision support system based on the Asynchronous Advantage Actor–Critic algorithm, which can significantly improve emergency evacuation efficiency at airports and in cabins, reducing average evacuation time by 43.86 %. The system outperforms the deep Q-network algorithm in dynamic environments, effectively enhancing personnel safety and evacuation efficiency. Alam et al. [16] developed an airport evacuation micro-simulation model that incorporates pedestrian socio-physiological behaviour. Under low-panic scenarios, the model predicts that pedestrians will adjust their movement in response to increased network bottlenecks and may exhibit cooperative behaviour by controlling their speed as crowd density rises. In high-panic scenarios, it simulates that pedestrians lose behavioural control, exacerbating evacuation difficulties. Despite progress in algorithm and behavioural mechanism, most studies have focused on localized factors or idealized scenarios. Systematic simulation and optimization that consider overall terminal spatial layout and the coupling effects of multichannel resource allocation and pedestrian flow convergence are lacking. This situation makes supporting the development of dynamic evacuation strategies that are tailored to different operational states difficult.

In summary, significant progress has been achieved in the evacuation risk assessment and optimization strategy development for airports. However, existing studies still exhibit shortcomings in areas such as multidisciplinary model integration and evacuation procedure optimization. On the one hand, with regard to multidisciplinary model integration, e.g., the combination of gas dispersion models and pedestrian movement models, existing study frequently lacks empirical validation, resulting in limited practical applicability. On the other hand, although evacuation procedure optimization can alleviate evacuation congestion and reduce evacuation time to a certain extent, study on scenario-specific and airport-type-adapted optimization strategies remains insufficient, and thus, meeting actual emergency evacuation demands is difficult.

3. METHODOLOGY

3.1 Introduction to the case study

Airport terminals typically comprise facilities such as waiting halls, arrival and departure services, baggage handling systems, airline services, commercial services, and security installations. They primarily provide services to passengers, including check-in and boarding procedures, baggage check-in, retrieval and storage, ticketing, refunds and changes, dining, shopping, and entertainment. As such, terminals represent one of the most densely populated areas where passengers gather before boarding.

As a major aviation hub in Central China, Zhengzhou Xinzheng International Airport has experienced sustained growth in passenger traffic in recent years. During the 2024 Spring

Festival travel season, the airport handled a total of 25,000 inbound and outbound flights, serving over 3.3 million passengers. The single-day passenger peak reached 99,500, setting a historical record and reflecting the airport's critical role as a high-density passenger distribution centre. The aerial view of Terminal T2 exhibits an "X"-shaped layout, consisting of the main terminal building, four concourses (southeast, northeast, southwest, and northwest), and internal connecting corridors. The terminal accommodates domestic and international flights. Internally, the terminal building spans five levels, including the arrival floor, the remote gate departure floor, and the departure floor. The departure hall, which serves as the area where passengers rest and wait before boarding, has the highest concentration of people. Therefore, the current study selects the fourth floor departure hall of Zhengzhou Xinzheng Airport Terminal T2 as the object of simulation practice. This level houses check-in islands B through G: domestic flight check-in counters are located at islands B, C, D, E, and F, while island G is designated for international flight check-in. In addition, this floor contains multiple waiting lounges, rest areas, shops, restaurants, restrooms, and other public facilities. The layout of the departure hall is illustrated in Fig. 1.

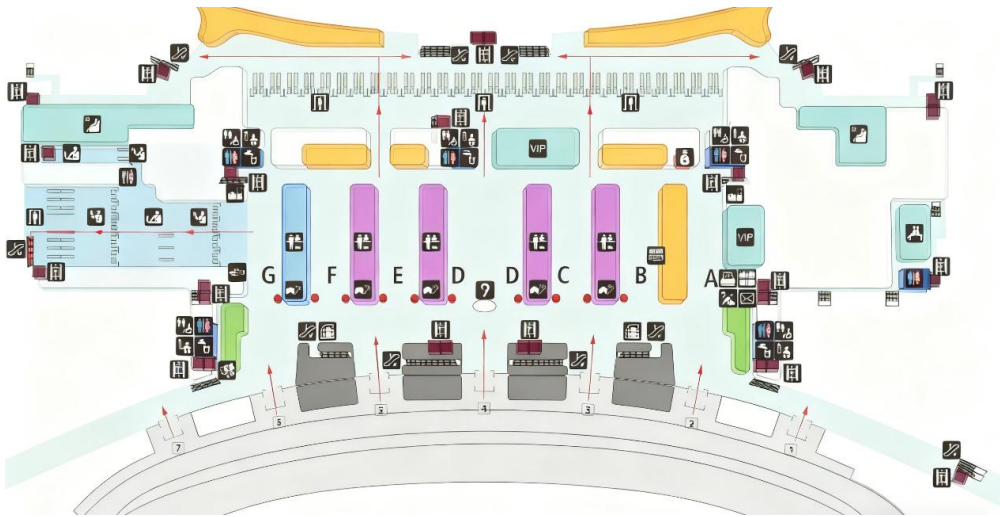


Figure 1: Layout plan of the terminal departure hall.

3.2 Construction of the simulation model

The emergency evacuation simulation model for an airport terminal departure hall is largely constructed using the Pedestrian Library in AnyLogic simulation software. The specific modelling process is as follows [17, 18].

(1) The floor plan of the departure hall at Xinzheng Airport was imported into the main workspace of AnyLogic software to establish the background map.

(2) The physical model was constructed using modules from the Pedestrian Library over the background map. This model incorporates terminal walls, check-in counters, security check channels, shops, lounges, and other relevant elements. Their properties were configured by modifying parameters within the corresponding modules.

(3) Pedestrian behaviour modules were added and connected to build the logical relationship diagram that governs pedestrian movement.

(4) Parameters were adjusted, or Java code was inserted into the behaviour modules, to define the properties of each component.

(5) The simulation results were analysed based on data, including pedestrian density, total evacuation time, and number of pedestrians evacuated per unit time.

The simulation scenario was constructed on the basis of the social force model. The resultant force acting on a pedestrian comprises the driving force, interaction forces,

environmental forces, and a random fluctuation term. These force components collectively determine the movement trajectory, and the mathematical expression is as follows:

$$m_i \frac{d\vec{v}_i(t)}{dt} = \vec{F}_i(t) + \vec{\zeta}(t) \quad (1)$$

where m_i : mass of pedestrian i , $m_i \frac{d\vec{v}_i(t)}{dt}$: instantaneous acceleration of pedestrian i , $\vec{F}_i(t)$: resultant force acting on pedestrian i , and $\vec{\zeta}(t)$: random variable that describes the stochastic behaviour of pedestrian i .

$$\vec{F}_i(t) = \vec{f}_{0i} + \sum_{j \neq i} \vec{f}_{ij} + \sum_w \vec{f}_{iw} \quad (2)$$

where \vec{f}_{0i} : self-driving force of pedestrian i , $\sum_{j \neq i} \vec{f}_{ij}$: sum of interactive forces exerted on pedestrian i by all other pedestrians j , and $\sum_w \vec{f}_{iw}$: sum of forces exerted on pedestrian i by walls/obstacles w .

To enhance the computational efficiency of the model and emphasize the key factors that influence emergency evacuation in an airport departure hall, the following simplifications and assumptions are incorporated into the simulation model:

(1) Simulation scope. The interior of the departure hall is defined as the evacuation environment, excluding areas outside the entrance and exit gates.

(2) Simplification of interior facilities. Objects with relatively small footprints inside the hall, such as seats and pillars, are omitted. Elevators and escalators are assumed to be non-operational during a fire emergency.

The emergency evacuation simulation model for an airport terminal departure hall is illustrated in Fig. 2.

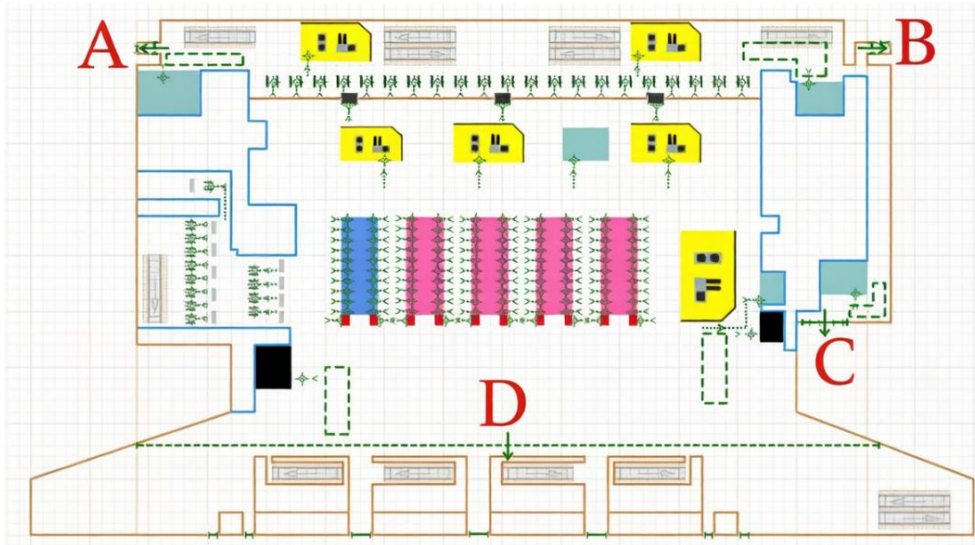


Figure 2: Construction of the simulated physical environment for the departure hall.

3.3 Simulation parameter settings

Emergency evacuation in a terminal departure hall focuses on passengers, and thus, the simulation parameters to be set in the model include pedestrian dimensions, walking speeds, and passenger flow rates.

Pedestrian dimensions: During evacuation, the body size of pedestrians affects the capacity of exits and passageways. Therefore, the shoulder width of pedestrians is determined with reference to the anthropometric dimensions of Chinese adults, as detailed in Table I.

Table I: Statistical table of shoulder width for adults.

Gender	Shoulder breadth /mm	Maximum shoulder breadth /mm
Male	415	486
Female	387	458

According to the table data, pedestrian dimensions in the simulation model are set to follow a uniform distribution that ranges from 0.4 m to 0.5 m.

Pedestrian speed: Different types of passengers have different horizontal walking and stair-climbing speeds. The study object in this work is a single floor, and thus, stair movement is disregarded, and only the horizontal walking speed of passengers is considered. The average speed of pedestrians is 1.07 m/s, with the elderly and children moving slower than the average. In the simulation modelling, pedestrian speed is set to follow a uniform distribution that ranges from 1 m/s to 1.2 m/s.

Passenger flow: During the 2024 Spring Festival travel rush, Zhengzhou Airport handled a total of 25,000 inbound and outbound flights, with a maximum daily flight volume of 671. The passenger throughput exceeded 3.3 million, with an average daily passenger flow of about 83,000 and a maximum daily passenger volume of 99,500, setting a new historical record for Zhengzhou Xinzheng International Airport since its opening in 1997. On the basis of these data, pedestrian passenger flow in the simulation model is set to an average of 50 people per minute.

4. RESULT ANALYSIS AND DISCUSSION

4.1 Design of emergency evacuation simulation scenarios

Based on the actual operation of the airport terminal departure hall, the number of open security check channels is directly related to passenger flow, weather conditions, flight volume, and other factors. Therefore, the following simulation scenarios are considered for setup (Table II).

Table II: Simulation scenario design.

Scenario category	Scenario description
Scenario 1	This scenario considers that if some flights are suspended due to weather or other reasons, the corresponding security check channels will be closed. It is assumed that the suspended flights mainly correspond to the security check channels on the right side, meaning only the security check channels on the left side are open.
Scenario 2	This scenario is similar to Scenario 1, but it assumes that the suspended flights mainly correspond to the security check channels on the left side, meaning only the security check channels on the right side are open.
Scenario 3	The airport operates normally without any special circumstances; however, in the event of an emergency, two security channels will be opened for the evacuation of personnel.

Analysis of simulation results for Scenario 1: This scenario considers the closure of corresponding security check channels if flights are grounded due to reasons such as weather. The grounded flights are assumed to correspond primarily to the security check channels on the right side, i.e., only the left-side security check channels remain operational.

From the pedestrian evacuation density distribution map obtained through simulation (Fig. 3), the following spatial distribution characteristics can be observed. Near Evacuation Exit 1 in the upper section, localized high-density clustering is evident, reflecting the initial crowding effect at the exit area during the early stages of evacuation. In the region of Evacuation Exit 2, flow lines extend along the right-side corridor, with densities predominantly within the blue-green range, indicating relatively smooth pedestrian movement in this area. The central

core evacuation zone, which acts as a convergence node for multiple flow lines, exhibits overall low to medium density. However, flow lines converge at spatial constraints such as structural columns, suggesting potential congestion risks. A significant high-density cluster appears in the area below Entrances/Exits 3 and 4 in the lower section, where flow lines are highly concentrated, identifying this area as a critical congestion bottleneck within the overall evacuation path.

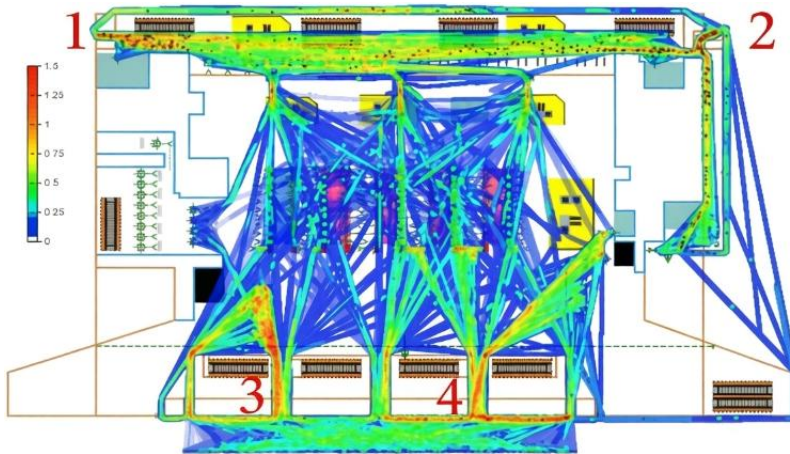


Figure 3: Emergency evacuation density distribution for Scenario 1.

To evaluate further the time required for pedestrian evacuation, a statistical analysis was conducted on 200 randomly selected sample data points. Evacuation times predominantly fall within the range of 0 s to 750 s, with the majority concentrated below 200 s, while a few individual samples lie between 200 s and 750 s. Under this scenario, the median evacuation time is 208.35 s, and the mean evacuation time is 258.47 s.

Analysis of simulation results for Scenario 2: Scenario 2 assumes that only the right-side security gates are operational, with all other settings remaining unchanged. The pedestrian evacuation density distribution map obtained from the simulation of Scenario 2 (Fig. 4) reveals the following characteristics. In the upper section near Evacuation Exit 1, flow lines are predominantly blue-green, indicating relatively smooth pedestrian movement in this area. By contrast, the region near Exit 2 shows high-density clustering in yellow-orange to red hues, demonstrating a pronounced localized crowding effect at the exit during the initial evacuation phase. Similar to Scenario 1, the central core evacuation zone exhibits an overall low to medium density of pedestrian flow lines. However, crowd aggregation density increases noticeably from the centre outward, suggesting the presence of certain potential congestion risks.

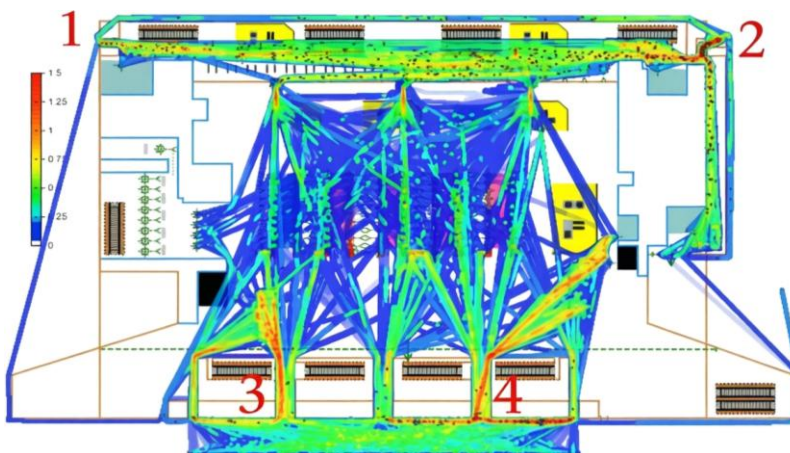


Figure 4: Emergency evacuation density distribution for Scenario 2.

A statistical analysis was performed on 200 randomly selected pedestrian evacuation samples. Evacuation times are predominantly concentrated within the range of 0 s to 650 s, with the majority of evacuation times below 200 s. A few individual samples fall within the range of 200 s to 650 s. The median evacuation time for this scenario is 165.77 s, and the mean evacuation time is 223.63 s, due to the outward-extending corridor at the right-side evacuation exit.

Analysis of simulation results for Scenario 3: Scenario 3 considers the airport operating under normal conditions, with two additional safety channels opened for pedestrian evacuation in the event of an emergency. After the initiation of emergency evacuation, the number of escape routes for pedestrians increases from the original nine to eleven, with the two additional ones being the leftmost and rightmost channels at the bottom. As shown in the simulation results of this scenario (Fig. 5), the pedestrian aggregation density at the upper No. 1 and No. 2 evacuation exits changes slightly. However, pedestrian density inside No. 3 and No. 4 exits decreases due to the addition of evacuation channels, while the crowd aggregation effect outside the exits becomes significant, improving evacuation efficiency to a certain extent.

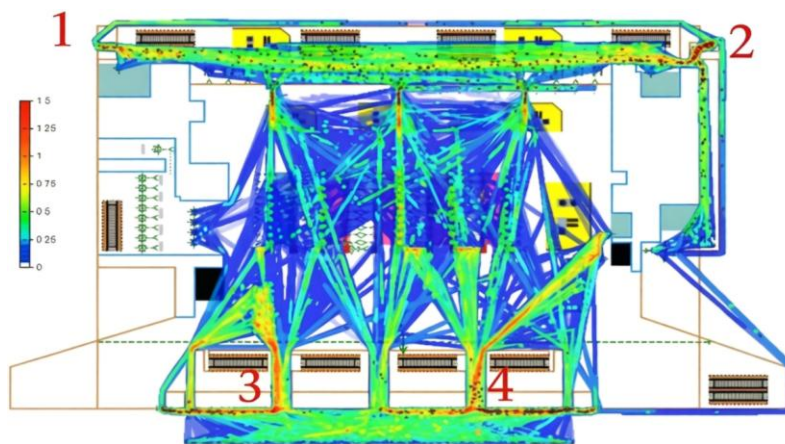


Figure 5: Emergency evacuation density distribution for Scenario 3.

Based on the statistical analysis of the selected 200 sample data points, pedestrian evacuation times in Scenario 3 predominantly fall within the range of 0 s to 750 s. The majority of evacuation times are below 200 s, while a few individual samples lie between 200 s and 750 s. The median evacuation time for this scenario is 172.04 s, and the mean evacuation time is 235.33 s.

Evacuation Exit 1 in the upper section of Scenario 1 and Evacuation Exit 2 in the upper section of Scenario 2 exhibited high-density clustering during the initial evacuation phase, resulting in reduced passage efficiency at the outset. In Scenario 1, the area around Entrances/Exits 3 and 4 in the lower section emerged as a critical congestion bottleneck, with flow lines heavily concentrated there. The central core evacuation zone, serving as a convergence node for multiple flow lines, demonstrated flow-line aggregation in Scenarios 1 and 2. Moreover, aggregation density in Scenario 2 increased noticeably outward from the central area. This condition was further intensified by spatial constraints such as structural columns, which heightened the risk of congestion.

When only one side of the security check channels is open (Scenarios 1 and 2), pedestrian flow becomes excessively concentrated on the corresponding side, while channel resources on the other side remain underutilized. Overall, passenger flow around Evacuation Exits 3 and 4 is significantly greater than at other exits, resulting in concentrated evacuation pressure, while the capacity of the remaining exits is not fully utilized. In Scenario 3, the two newly added evacuation passages fail to divert the crowd effectively due to their smaller dimensions and peripheral locations. Consequently, their contribution to improving overall evacuation outcome is limited, and the core congestion issue remains unresolved.

4.2 Optimization design for airport terminal emergency evacuation

The simulation of emergency evacuation in airport terminal departure halls has revealed the following key issues during the evacuation process. First, localized high-density crowding tends to occur at certain evacuation exits during the initial phase of evacuation, and the central core evacuation zone, as a convergence point of multiple flow lines, presents potential congestion risks. Spatially, Evacuation Exits 3 and 4 constitute the main evacuation bottlenecks. Second, the allocation of evacuation passage resources is suboptimal: when security check channels are open only on one side, pedestrian flow becomes excessively concentrated on that side while resources on the opposite side remain underutilized. Pedestrian flow around Evacuation Exits 3 and 4 is significantly higher than at other exits, leading to concentrated pressure, and the two additional evacuation passages introduced in Scenario 3 fail to serve as effective flow distributors due to their limited dimensions and peripheral locations.

Analysis of emergency evacuation optimization for Scenario 1: Only the left-side security gates are open in Scenario 1, and thus, pedestrian density in Area 1 is higher than in Area 2, and evacuation times for Areas 1 and 2 are slightly longer than those for Areas 3 and 4. Therefore, the adopted optimization measure is to redirect passengers who have not yet passed through the metal detectors to evacuate via Areas 3 and 4. The statistical data chart at the same simulation time step after optimization is shown in Fig. 6. The median evacuation time after optimization is 189.83 s, and the mean evacuation time is 233.29 s. Compared with the pre-optimization median of 208.35 s, the post-optimization median decreased by 18.85 s, and the mean decreased by 25.18 s from the pre-optimization value of 258.47 s. The reduction in median and mean values collectively reflects improved evacuation efficiency and shorter evacuation times after optimization, verifying the feasibility of the proposed optimization measure.

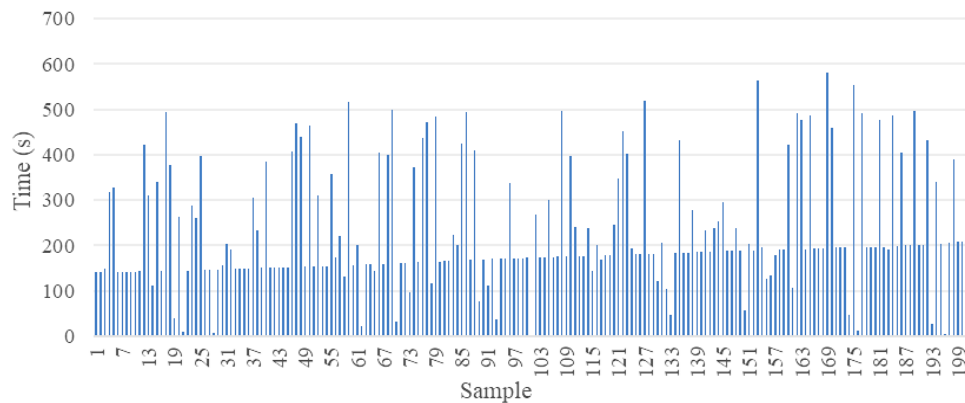


Figure 6: Statistical distribution of pedestrian evacuation time for the optimized Scenario 1.

Analysis of emergency evacuation optimization for Scenario 2: Only the right-side security gates are open in Scenario 2, and thus, pedestrian density in Area 1 is higher than in Area 2, and evacuation times for Areas 1 and 2 are slightly longer than those for Areas 3 and 4. Therefore, the optimization measure for this scenario involves redirecting passengers who have not yet passed through the metal detectors to evacuate via Areas 3 and 4. The statistical data chart at the same simulation time step after optimization is shown in Fig. 7. After optimization, the median evacuation time is 174.3 s, and the mean evacuation time is 218.45 s. Compared with the pre-optimization median of 165.77 s, the post-optimization median increased by 8.53 s. Conversely, compared with the pre-optimization mean of 223.63 s, the post-optimization mean decreased by 5.18 s. The reduction in mean value indicates a decreased central tendency in the sample data after optimization, corresponding to shorter evacuation times. The increase in median suggests a slight rise in the mid-level value of the sample dataset.

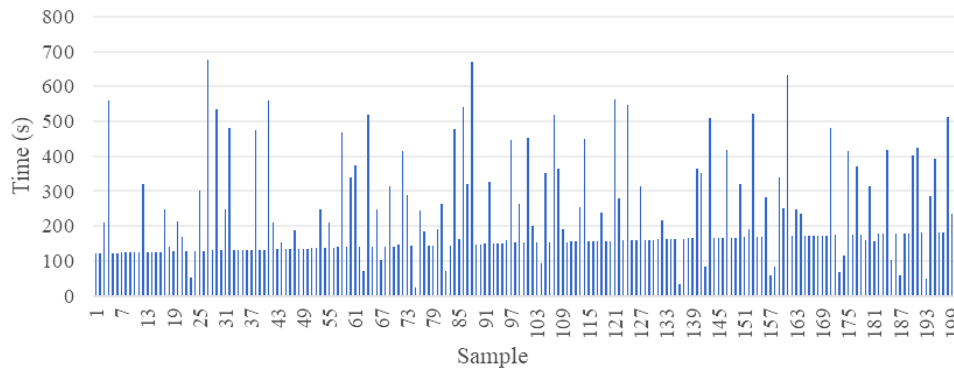


Figure 7: Statistical distribution of pedestrian evacuation time for the optimized Scenario 2.

Analysis of emergency evacuation optimization for Scenario 3: Although two additional evacuation passages were introduced in Scenario 3, resulting in a reduced occupant density in Areas 3 and 4, evacuation efficiency did not improve effectively, and the crowding phenomenon still occurred in front of the security check area. Therefore, the optimization strategy involves redirecting passengers who have not passed through the metal detectors to evacuate via Areas 3 and 4 and their adjacent lateral passages, while also implementing flow diversion for occupants who are originally scheduled to evacuate through Areas 3 and 4. The statistical data chart at the same simulation time step after optimization is shown in Fig. 8. After optimization, the median evacuation time is 175.05 s, and the mean evacuation time is 201.51 s. Compared with the pre-optimization median of 172.04 s, the post-optimization median increased by 3.01 s. Conversely, compared with the pre-optimization mean of 235.33 s, the post-optimization mean decreased by 33.82 s.

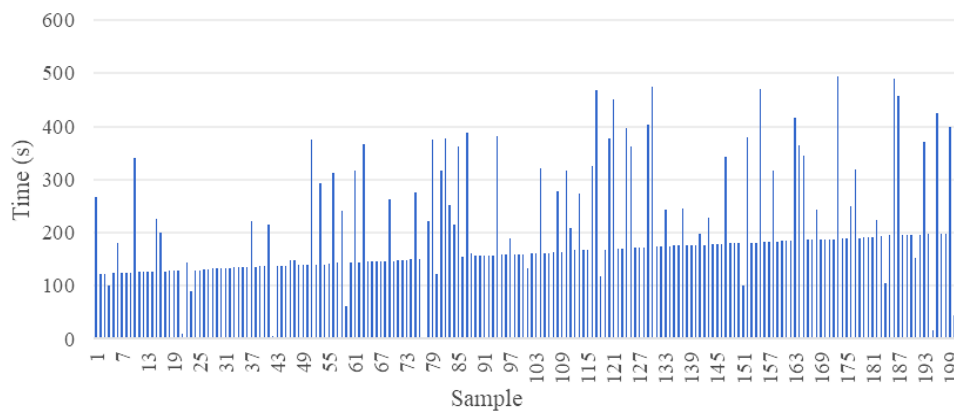


Figure 8: Statistical distribution of pedestrian evacuation time for the optimized Scenario 3.

In summary, for the three emergency evacuation scenarios in the airport terminal departure hall, the implemented optimization effectively alleviated the bottleneck effects in the originally congested areas. Comparing the effectiveness of the three optimization measures, the solution for Scenario 3 yielded the most effective improvement, achieving the largest reduction in mean evacuation time and the highest overall evacuation efficiency. The optimization for Scenario 1 ranked next, effectively lowering median and mean evacuation times, resulting in better evacuation stability. Although the optimization for Scenario 2 reduced mean evacuation time, the median value slightly increased, and evacuation times for some individual samples extended, indicating relatively lower optimization effectiveness. Overall, the emergency evacuation efficiency of airport terminal departure halls can be effectively improved by rationally distributing pedestrian flow and expanding evacuation passages. Among these, the combined strategy of opening additional passages alongside multi-zone flow diversion proved to be the most effective.

5. CONCLUSION

This study selected the fourth floor departure hall of Terminal T2 at Zhengzhou Xinzheng Airport as the case study. An emergency evacuation model was constructed based on the AnyLogic simulation platform. By designing three typical scenarios to simulate the evacuation process under different operational conditions, evacuation bottlenecks were identified and optimization strategies were proposed. The effectiveness of the strategies was subsequently validated. The major conclusions drawn are as follows:

(1) Significant initial crowding occurs at localized evacuation exits, easily forming high-density congestion bottlenecks. The central core evacuation zone also presents potential congestion risks due to the convergence of multiple flow lines. Evacuation passage resources are allocated suboptimal: when security check channels are open on one side only, pedestrian flow becomes excessively concentrated on that side while resources on the opposite side remain underutilized, resulting in insufficient passage utilization. Moreover, newly added passages fail to function effectively as flow distributors due to their limited dimensions and peripheral locations. Evacuation efficiency and temporal stability are inadequate. Across all three scenarios, a considerable disparity in pedestrian evacuation times is observed, and evacuation efficiency for a portion of occupants remains low.

(2) In Scenario 1, median and mean evacuation times were reduced by 18.85 s and 25.18 s, respectively, by redirecting land-side pedestrian evacuation routes. Scenario 2 applied the same diversion logic, resulting in a reduction of the mean evacuation time by 5.18 s. In Scenario 3, mean evacuation time was reduced by 33.82 s through multi-zone diversion combined with channel-flow guidance, representing the largest improvement among the three scenarios.

(3) The combined strategy of opening additional passages alongside multi-zone flow diversion provided the best outcomes. It not only alleviated congestion in core areas but also balanced the utilization of passage resources, significantly enhancing evacuation efficiency and stability.

In summary, this AnyLogic-based study reveals the “structure–flow–efficiency” interaction in terminal evacuation and demonstrates the feasibility of system optimization through scientific flow design and resource allocation. However, it treats pedestrians as perfectly rational, not fully accounting for socio-psychological factors like panic and herd behaviour. Future work should incorporate the social force model or empirical data to explore evacuation dynamics under bounded rationality, enhancing model realism and predictive capability for better support in emergency management theory and practice.

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