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TRAFFIC AND PEDESTRIAN EMERGENCY SIMULATION FOR RAILWAY STATION FORECOURTS

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Abstract: The railway station forecourt is a critical node in the urban transportation network, where traffic organization and emergency evacuation capabilities directly impact public safety and operational efficiency. This study utilizes the AnyLogic simulation platform to construct a multidimensional simulation system for a small railway station forecourt along the Chengdu-Chongqing Midline Railway. By incorporating multi-agent modeling, the research develops a hybrid simulation model that comprehensively accounts for the coupled dynamics of vehicle traffic, pedestrian flow, and environmental factors, overcoming the limitations of traditional single-dimensional simulations. A dynamic simulation engine driven by real-time data enhances the prediction accuracy of emergency responses. The simulation analysis identifies key issues, including lane design constraints, insufficient traffic signal control, complex transfer flows, and inadequate emergency evacuation capacity. Optimization measures are proposed, such as dedicated lane allocation, intelligent signal control, parking management improvements, and enhanced pedestrian guidance. This study provides a scientific foundation for spatial design optimization, graded emergency planning, and the enhancement of emergency management capabilities at small railway station forecourts, offering valuable reference for transportation hub planning in China.
Keywords: Railway station forecourt; Emergency evacuation; Multi-agent modeling; AnyLogic simulation

1 INTRODUCTION

The railway station square is a crucial node in the urban transportation network, and its traffic organization and emergency evacuation capabilities directly impact urban public safety and operational efficiency. In recent years, with the rapid development of pedestrian micro-simulation technology, emergency simulation based on multi-agent modeling has become a research hotspot.
The integration of multi-agent systems into emergency simulations allows for a more nuanced understanding of pedestrian dynamics in complex environments. This approach is particularly beneficial in scenarios such as railway station forecourts, where the interaction between pedestrians and vehicles can significantly affect evacuation efficiency. For instance, research on pedestrian collective motion in competitive evacuation scenarios highlights the importance of considering both density and kinetic stress to accurately model pedestrian behavior under pressure [1]. This is crucial for designing effective evacuation strategies that can be implemented in real-time during emergencies.
Moreover, the application of social force models in pedestrian motion studies provides insights into how individuals navigate through crowded spaces, which is essential for optimizing traffic flow and ensuring safety in railway station forecourts [2]. These models simulate the forces exerted by individuals as they move, allowing for the prediction of potential bottlenecks and the development of strategies to mitigate congestion.
In addition to pedestrian dynamics, the resilience of transportation networks during disruptive events is a critical area of study. For example, modeling the resilience of rail passenger transport networks affected by large-scale disruptive events, such as earthquakes, can inform the development of robust emergency response plans [3]. This research underscores the importance of understanding the infrastructural and operational conditions that influence network resilience, which can be applied to railway station forecourts to enhance their emergency preparedness.
Furthermore, the use of intelligent transportation systems, such as cooperative adaptive cruise control, can improve traffic management in urban areas, including railway station forecourts. These systems leverage connected vehicle technologies to optimize traffic flow and reduce congestion, thereby enhancing the overall efficiency of the transportation network [4].
Finally, the integration of advanced simulation models, such as those combining urban mobility, flood inundation, and sewer hydrodynamics processes, can provide a comprehensive assessment of urban drainage systems' resilience. This holistic approach is vital for understanding the interplay between human behavior and infrastructure during emergencies, particularly in areas prone to flooding [5].
In the realm of passenger station emergency management, the operations adhere to the overarching requirements of the railway's general emergency management system [6]. The passenger station emergency management system encompasses "one plan and three mechanisms" [7], spanning the pre-event, in-event, and post-event phases of emergencies. During emergency response, station leaders at various levels convene at the emergency command center to deliberate and formulate emergency response tasks based on the station's emergency plans. Subsequently, department

leaders disseminate these tasks to staff for execution, followed by summarization and recovery post-response. Throughout this process, the formulation of emergency plans relies entirely on the emergency plans and the experience of the leading group, while the execution of response tasks depends solely on individual experience. The completion status of each critical response link is autonomously reported by on-site staff.

In the field of railway station emergency management, numerous domestic scholars have conducted research. Yang Bowen [8], taking Tianjin Station as an example, studied the evaluation index system of the "one plan and three mechanisms" for emergency management in response to public emergencies. Liu Congcong [9] investigated the emergency response mechanisms for sudden violent incidents at passenger stations. Song Junfu [10] explored the evaluation methods of station operators' emergency response capabilities from the perspectives of safety awareness and response ability. Wang Pu [11] and others, employing enterprise architecture theory, designed the business, application, information, and technical architecture of a high-speed railway emergency platform, covering headquarters, regional, and on-site levels, thereby achieving comprehensive emergency management across all tiers of high-speed railways.

AnyLogic as a simulation platform supporting discrete event, system dynamics, and multi-agent hybrid modeling, demonstrates unique advantages in simulating dynamic interactions within complex scenarios. Its flexible multi-method modeling capabilities and visual interface make it one of the preferred tools for simulation research in transportation hubs. This study, based on the engineering context of a station square along the Chengdu-Chongqing Midline Railway, constructs a multi-dimensional simulation system through AnyLogic. At the theoretical level, it establishes a hybrid model considering the coupling effects of traffic, pedestrians, and the environment, breaking through the limitations of traditional single-dimensional simulations. At the methodological level, it develops a dynamic simulation engine driven by real-time data, enhancing the prediction accuracy of emergency response. The research outcomes provide scientific basis for the spatial optimization design of station squares, the formulation of graded emergency plans, and the improvement of emergency management capabilities at passenger hubs, offering significant socio-economic benefits and engineering application value.

2 SIMULATION MODEL

The simulation model of the station square consists of a geometric model and a logical model. The geometric model is used to create the station square roads and various buildings, while the logical model is used to construct the logical relationships between vehicles and pedestrians. The geometric model is the foundation of the simulation model, providing the physical environment through precise spatial layout and building structures. The logical model is the core of the simulation, defining the behavioral rules, interaction mechanisms, and dynamic decision-making processes of vehicles and pedestrians, simulating the actual operation of traffic and pedestrian flows in the station square.

2.1 Geometric Model

AnyLogic's Road Traffic Library provides efficient and flexible tools for modeling complex traffic systems. The construction of the lane network is the foundational step in traffic simulation. This paper uses the "Road" element to draw the lane network. By dragging the "Road" element from the traffic library to the drawing area and continuously clicking the left mouse button, nodes are created and connected to form the lane network. The lane's attribute parameters (such as width, speed limit, number of lanes, etc.) are configured according to the actual scene requirements. In the simulation model of the railway station square, a one-way dual-lane road is set up to simulate the traffic needs of taxis and social vehicles. The geometric model of the station square are shown in Figure 1.

The bus stop, as an important traffic facility in the station square, requires modeling that considers vehicle stopping and passenger boarding and alighting behaviors. This paper uses the "Bus Stop" element to simulate the bus stop. Specific steps include placing the "Bus Stop" element next to the lane and setting key parameters such as stopping time and capacity. Additionally, by connecting the "Ped Wait" element with the "Bus Stop," the waiting behavior of passengers at the stop can be simulated. Based on actual operational data, the stopping time during peak hours is set to 2 minutes, and during off-peak hours, it is set to 1 minute to reflect the operational characteristics of different periods.

The modeling of the parking lot is an important part of the traffic organization in the station square. The "Parking Lot" element can be used to simulate vehicle parking and departure behaviors. Specific implementations include setting the parking lot's capacity, entrance and exit positions, and connecting it to the lane network using the "Road" element. In the road model, a parking lot with a capacity of 40 vehicles is set up to simulate the parking and departure processes of taxis and social vehicles.

Traffic lights are key facilities for controlling vehicle and pedestrian traffic at intersections. This paper uses the "Traffic Light" element to achieve timing and phase control of traffic lights. Specific steps include placing the "Traffic Light" element at the intersection and connecting it to the lane network using the "Road Network" element. A two-phase traffic light is set up on the road to simulate pedestrian crossing behaviors at the intersection with the station square.

The design of pedestrian walkways is a core aspect of pedestrian flow simulation. This paper uses the "Pedestrian Road" element to draw the pedestrian walkway network. Specific implementations include setting up "Crosswalk" elements where "Pedestrian Road" and "Road" elements intersect to simulate pedestrian crossing behaviors. Additionally, the "Ped Source" and "Ped Sink" elements can be used to simulate the generation and disappearance of pedestrians. In the model, pedestrian walkways are set up to connect the station square with surrounding facilities, simulating the dynamic distribution characteristics of pedestrian flows.

After completing the setup of the above elements, the "Car Source" and "Car Sink" elements are used to simulate the generation and disappearance of vehicles, and the interaction functions of the "Pedestrian Library" and "Road Traffic Library" are utilized to achieve mixed vehicle-pedestrian simulation. Finally, model performance is optimized through parameter adjustment and experimental design. By adjusting traffic light timing to reduce vehicle queue lengths or optimizing bus stop positions to improve pedestrian flow efficiency.

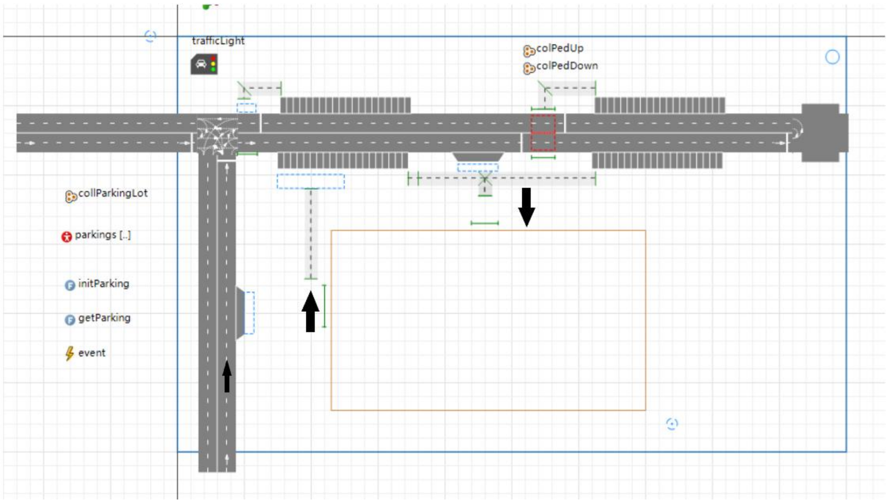

Figure 1 Geometric Model of the Station Square

2.2 Logical Model

This study is based on a railway station square, using simulation technology to simulate the traffic and pedestrian emergency response in the square area, covering vehicle travel, parking management, pedestrian flow, traffic signal control, and emergency incident handling. The constructed simulation system comprehensively analyzes vehicle traffic flow, pedestrian flow, and bus transfers, evaluating the square's traffic adaptability under normal and emergency conditions. Through modeling and optimization, the overall operational efficiency of the square is improved, providing scientific support for emergency traffic regulation.

2.2.1 Vehicle traffic flow logical model

This mainly includes three types of vehicles: social vehicles, taxis, and buses, with simulations conducted for the different traffic and parking management methods of each type. Social vehicles can enter temporary parking areas, and if no spaces are available, they enter waiting areas to queue. Taxis enter designated waiting areas and proceed to specified boarding and alighting areas in the station square in order. Buses stop at designated stops around the square at scheduled times and follow fixed routes. During the simulation, path planning algorithms control vehicle flow directions, and parking management systems dynamically adjust traffic flow to ensure traffic efficiency. Additionally, the square's traffic signals use dynamic control modes, adjusting traffic light durations based on real-time traffic flow, and can switch to special modes (such as emergency passage modes) during emergencies to enhance emergency response capabilities. During emergencies, the system adjusts traffic organization methods, including restricting social vehicle entry, accelerating taxi dispatch, and increasing bus capacity, thereby improving the square's traffic response capabilities. The parking space collection and parking lot agent definitions are shown in Figure 2, vehicle alighting logical process are shown in Figure 3,and the social vehicle boarding and alighting logical model is shown in Figure 4.

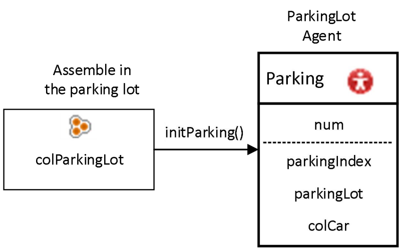

Figure 2 Parking Space Collection and Parking Lot Agent Definition

2.2.2 Pedestrian flow logical model

This mainly includes three types of pedestrians: ordinary passengers, pick-up and drop-off personnel, and emergency evacuation crowds. Ordinary passengers move within the station square, completing entry, exit, and transfer processes; pick-up and drop-off personnel stay briefly before leaving the square; emergency evacuation crowds quickly evacuate according to guidance during emergencies. The main pedestrian passage method connects different areas through ground walking. The simulation model uses path selection algorithms to allow pedestrians to choose optimal paths based on target areas, dynamically adjusting walking speeds based on pedestrian density to improve simulation accuracy. The square's pedestrian crossing methods are mainly divided into unsignalized crosswalks and signal-controlled intersections. Under low traffic conditions, pedestrians can directly cross at crosswalks, with vehicles yielding to pedestrians when density is high; in high-traffic areas, signal control is used to optimize traffic efficiency. During emergencies, the simulation system adjusts pedestrian flow directions and activates emergency evacuation mechanisms, such as broadcasting guidance to direct pedestrians to safe exits to avoid ground congestion and coordinating vehicle evacuation to reduce pedestrian. Through simulation analysis of pedestrian flow characteristics, the pedestrian organization in the station square can be optimized, improving evacuation efficiency during emergencies.

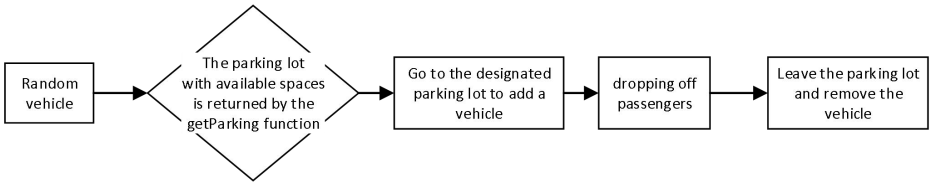

Figure 3 Vehicle Alighting Logical Process

2.2.3 Bus operation and passenger transfer

This mainly focuses on bus route settings, passenger boarding and alighting logic, and emergency transfer strategies. The bus system in the station square consists of multiple routes, and passengers can choose the appropriate route based on their destination. The simulation model establishes a bus operation schedule and dynamically adjusts departure frequencies based on passenger flow peaks to improve transfer efficiency. During passenger boarding and alighting, passengers queue at bus stops and board in order during normal transfers; during emergencies, bus departures are increased to enhance transport capacity and reduce passenger in the station square. Through simulation analysis of bus operation and transfer processes, the service capacity of the bus system in the station square can be effectively evaluated, providing optimization solutions for passenger flow peaks or emergencies. The bus vehicle boarding and alighting logical model is shown in Figure 5.

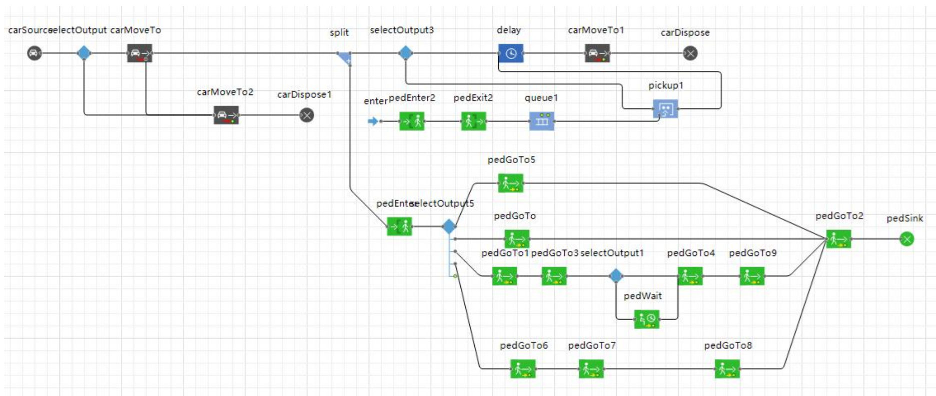

Figure 4 Social Vehicle Boarding and Alighting Logical Diagram

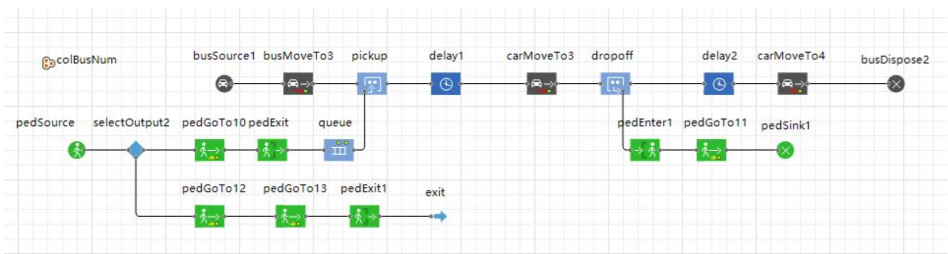

Figure 5 Bus Vehicle Boarding and Alighting Logical Diagram

3 SIMULATION ANALYSIS

This paper, based on the engineering context of a small railway station square along the Chengdu-Chongqing Midline, constructs a traffic simulation model of the station square using the AnyLogic simulation platform, simulating congestion levels under different vehicle and passenger flow conditions, analyzing traffic operation characteristics under different scenarios, and proposing reasonable improvement measures. The research covers traffic organization, pedestrian flow, signal control optimization, and emergency evacuation strategies in the station square, aiming to provide scientific basis for improving the traffic efficiency and safety management level of small railway station buildings. The simulation parameters are shown in Table 1, and the simulation results are shown in Figure 6.

Table 1 Simulation Parameters Table

Category	Ped Flow (per/h)	Car Traffic (pcu/h)	Bus Traffic (pcu/h)
Number	1000	500	100

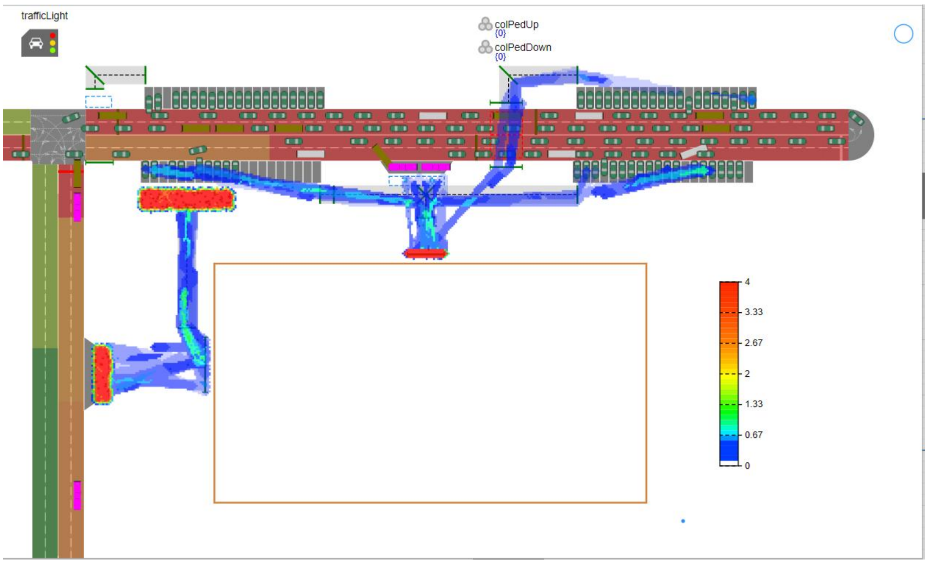

Figure 6 Simulation Analysis Results

3.1 Vehicle Traffic Flow Analysis

The simulation results show that during peak hours, the gathering of taxis and private cars easily leads to vehicle hold up at the entrance of the station square, affecting traffic efficiency. Especially when the parking lot is full, waiting vehicles queue on the road, further exacerbating congestion. Additionally, frequent stops by ride-hailing vehicles waiting for passengers reduce the speed of the main passageway, causing traffic bottlenecks.
Further analysis reveals that the traffic flow in the station square is mainly affected by the following factors:
The number and allocation of lanes affect traffic smoothness, especially the mixed traffic of social vehicles and taxis, which increases traffic conflicts.
The duration and phase settings of traffic lights are crucial for the connection of traffic inside and outside the station square. Optimizing signal control can effectively alleviate congestion during peak hours.
The capacity limit of parking areas causes some vehicles to temporarily stop on the main road, increasing traffic load.

3.2 Passenger Flow Analysis

The passenger flow in the station square is mainly concentrated at the entrance, exit, and bus stop areas. During peak hours, the gathering of transfer passengers may cause blockages in pedestrian passageway, affecting the efficiency of passenger entry and exit. Especially in the absence of reasonable passenger flow guidance measures, the random movement of passengers reduces overall traffic capacity.
Through simulation analysis of different passenger flow scenarios, the following issues are identified:
(1) The complex transfer paths of passengers lead to excessive gathering in some areas.
(2) The limited capacity of bus stops makes it difficult to meet the transfer require of large passenger flows during peak hours.
(3) The limited walking space in the station square, especially when there are many social vehicles, interferes with pedestrian flow.

3.3 Congestion Cause Analysis

(1) lane design issues: the forecourt of small stations often has a limited number of lanes, which can easily create bottlenecks during peak traffic hours.
(2) insufficient traffic light control: the current traffic light settings may not effectively regulate the flow of vehicles and pedestrians, disrupting traffic order.
(3) complex transfer flow: the lack of reasonable guidance measures for passengers transferring between different modes of transportation leads to crowded pedestrian flows.

(4) Inadequate Emergency Evacuation Capacity: In emergencies, the forecourt lacks channels and organizational plans for rapid dispersal, impacting the safe evacuation of passengers.

4 OPTIMIZATION MEASURES FOR THE STATION FORECOURT

4.1 Vehicle Traffic Optimization

(1) Optimizing Lane Layout: Establish dedicated pick-up and drop-off lanes for taxis, separated from private vehicle connection areas, to reduce cross-interference. Add fast-track lanes at the entrance of the station forecourt to improve vehicle throughput efficiency.
(2) Intelligent Traffic Signal Control: Implement smart traffic lights that adjust green light durations based on real-time traffic flow. Optimize crosswalk placement in pedestrian-heavy areas to minimize conflicts between vehicles and pedestrians.
(3) Parking Management Optimization: Use electronic guidance systems to direct private vehicles to backup parking areas, enhancing parking efficiency. Establish temporary parking zones to reduce the dwell time of social vehicles.

4.2 Passenger Flow Optimization

(1) Optimizing Forecourt Flow Line Design: Create clear entry and exit flow lines to reduce chaos in passenger movement directions. Improve passenger transfer routes using ground markings and guidance screens.
(2) Increasing Pedestrian Pathways and Crossing Facilities: Widen pedestrian pathways to enhance capacity during peak periods. Install overpasses or underpasses to reduce direct intersections between pedestrians and vehicle traffic.
(3) Emergency Evacuation Management: Establish emergency evacuation routes and conduct regular drills. Utilize intelligent monitoring systems to analyze pedestrian density in real-time and provide dynamic dispersal solutions.

5 CONCLUSION

This article analyzed the vehicle and passenger flow characteristics of the forecourt of small railway stations through simulation and proposed optimization measures. The research findings indicate that through rational traffic organization, signal optimization, parking management, and passenger flow guidance, the forecourt's traffic efficiency can be effectively improved, congestion reduced, and the passenger travel experience enhanced. This study provides a reference for the planning and management of forecourts at small railway stations in China.
Furthermore, the results demonstrate that optimizing the station forecourt not only improves traffic fluidity but also enhances passenger safety and comfort. By reasonably allocating lanes and optimizing signal control, congestion points can be reduced, and vehicle throughput efficiency increased. Additionally, measures such as widening pedestrian pathways and rationally designing crossing facilities contribute to greater convenience for pedestrian movement.
In terms of emergency management, establishing comprehensive evacuation plans and intelligent monitoring systems can significantly enhance the forecourt's ability to respond to sudden incidents. Real-time monitoring of passenger flow, combined with dynamic traffic adjustments, enables rapid dispersal within a short timeframe, mitigating safety risks.
Future research could further integrate big data and artificial intelligence technologies to develop more advanced intelligent traffic management systems, thereby improving the operational efficiency and service quality of forecourts at small railway stations. Additionally, studies on differentiated optimization schemes tailored to the characteristics of different cities could be conducted to meet diverse regional needs.
This article analyzed the vehicle and passenger flow characteristics of the forecourt of small railway stations through simulation and proposed optimization measures. The research findings indicate that through rational traffic organization, signal optimization, parking management, and passenger flow guidance, the forecourt's traffic efficiency can be effectively improved, congestion reduced, and the passenger travel experience enhanced. This study provides a reference for the planning and management of forecourts at small railway stations in China.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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