Theory and Practice of Science and Technology
2025, VOL. 6, NO. 7, 25-29
DOI: 10.47297/taposatWSP2633-456905.20250607

Optimization of Ride-hailing Shuttle System Based on Automation Technology

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ABSTRACT
With the acceleration of urbanization and the increasing travel demands of residents, people's modes of transportation are becoming more diverse. Ride-hailing, as a convenient shared travel model, has increasingly highlighted the efficiency of shuttle services in special scenarios such as airports and railway stations. This paper proposes an optimization plan for the ride-hailing shuttle system based on automation technology, aiming to improve shuttle efficiency, reduce management difficulties, and enhance passenger experience through intelligent equipment and sensor networks.

KEYWORDS
Ride-hailing; Shuttle system; Automation technology; Sensor network

1 Research background and significance

1.1 Research background

With the rapid development of 5G, artificial intelligence, big data, and other technologies, people's modes of transportation are changing rapidly. According to the data from the National Taxi Supervision and Information Interaction System, from January to October 2024, 9.424 billion orders were completed, a significant increase of 27.44% compared to the same period in 2023. The peak month for orders was August (1.029 billion), while the lowest was February (775 million) [1]. The concept of traditional taxis is gradually being replaced by ride-hailing, essentially due to the change in the shuttle model of traditional taxis. Traditional taxis used to roam around the city to find passengers offline, which not only wasted resources and had low shuttle efficiency but also had limited shuttle facility space, lacked unified planning, and had high management and supervision difficulties[2]. Modern ride-hailing services, through mobile software platforms, enable online appointment and offline shuttle between drivers and passengers, significantly saving time for both parties.

1.2 Problem description

In major airports and railway stations, ride-hailing vehicles often park randomly around the station area, occupying traffic lanes and fire lanes, exacerbating congestion. Some passengers who try to hail a taxi offline may find that the signs in some airports and railway stations are old or discontinuous, requiring repeated phone calls with the driver to confirm the location. In some airports, passengers need to take an elevator to the underground second floor to find the pick-up point, which can take 5-10 minutes on foot[3]. Additionally, in some regions, taxis do not participate in app operations, and the ride information is incomplete. For travelers who want to take a taxi, they can only wait blindly. This situation naturally reduces passengers' satisfaction with their journey and increases the management difficulty of the shuttle system, further reducing overall comfort[4].

Ride-hailing, as a relatively new mode of transportation in recent years, was not considered in the planning and construction of airports in the past. According to general empirical rules, 100 to 300 parking spaces should be provided for every million boarding passengers, with 25% to 30% of the parking spaces designated for temporary parking[5]. However, ride-hailing vehicles mainly occupy temporary parking indicators, resulting in an insufficient supply of temporary parking facilities in existing airports.

1.3 Current status of research

Currently, some achievements have been made in the study of ride-hailing shuttle systems. Zhao Guihong[6] et al. studied the airport taxi service system from the perspective of "queuing theory," exploring the impact of different queuing arrangements on improving pick-up efficiency. This paper also noted the low efficiency of ride-hailing shuttles and the time-consuming coordination between passengers and drivers at shuttle hubs such as airports and railway stations. Taking Zhengzhou Xinzheng Airport as a case study, it mainly discussed the layout of taxi waiting areas and queuing models, arguing that a certain queuing mode should be adopted to maximize the use of limited shuttle space for the highest shuttle efficiency. However, it did not mention optimizing the shuttle mode with the help of sensor networks and Internet technology to fundamentally solve the problem that the traditional shuttle mode is no longer suitable for the new transportation hub model.

Yang Chaoran[7] et al. explored the design and optimization of an intelligent ride-hailing system based on 5G and autonomous driving technology, focusing on how to enhance the intelligence level of ride-hailing vehicles themselves. However, considering the actual shuttle level and capacity of most domestic airports and railway stations, as well as the current development status of domestic autonomous driving technology, it is difficult to use autonomous driving ride-hailing vehicles as a suitable means to improve the efficiency of the shuttle mode. Therefore, this study will fill this gap by setting up pick-up areas and vehicle storage areas and using various sensor networks to control vehicles at the network level, achieving a one-to-one correspondence between people and vehicles, standardizing the pick-up order, reducing queuing costs, and improving shuttle convenience.

2 Research content and results

2.1 Existing shuttle modes

Through field surveys of some domestic airports and railway stations, it was found that the existing ride-hailing shuttle modes mainly have the following problems,first, the long distance drivers have to travel to pick up passengers results in low operational efficiency, Second, inaccurate passenger positioning increases communication costs.Third, the difficulty of hailing a ride is particularly prominent at night or during peak hours[8].Fourth, there is an information asymmetry where passengers cannot obtain real-time information on vehicle arrival times and exact pick-up locations.

After conducting an eight-month field follow-up survey and semi-structured interviews with 12 large stations with an annual throughput of over 30 million passengers across the country, including Beijing Capital International Airport, Shanghai Hongqiao Hub, Guangzhou South Station, and Chengdu East Station, it was found that the current ride-hailing shuttle system is trapped in a "six-dimensional dilemma":

(1) Spatial Dimension Imbalance: The average straight-line distance for drivers to pick up orders reaches 1.8–3.2 km. In some airports like Terminal 3, due to runway obstruction, the detour distance can even exceed 5 km. This results in a daily effective mileage ratio of only 52% for individual vehicles, far lower than the average level of 78% for urban cruising taxis. Drivers, in an attempt to reduce empty driving, are forced to park illegally at the departure level, which further exacerbates congestion there[9].

(2) Positioning Dimension Inaccuracy: The GPS drift error for passengers in typical station scenarios such as overpasses and underground passages can reach 50 – 120 m. Coupled with the absence of indoor satellite signals, passengers and drivers need to confirm their positions through 5 – 8 rounds of voice communication, with an average communication time of 4.7 minutes. For international flight passengers arriving at night, the communication failure rate due to language barriers can be as high as 31%[10].

(3) Temporal Dimension Mismatch: During the 00: 00 – 05: 00 night shift and holiday return peaks, the ratio of instantaneous passenger flow at the station to the available ride-hailing capacity can reach 1: 0.3. The median waiting time for passengers is 28 minutes, and in extreme cases (such as on the first day of the Spring Festival travel rush at Guangzhou South Station), it can exceed 90 minutes. Meanwhile, 41% of ride-hailing vehicles within 3 km leave empty-handed due to the difficulty of entering the station[2].

(4) Information Dimension Lag: The existing system can only provide a single dimension of information, the "estimated arrival time," with an error range of ±8 minutes. Moreover, it cannot inform passengers of the specific parking lane where the vehicle will stop. Passengers have to move back and forth an average of 350 m in the arrival layer to find their vehicle. For passengers carrying large luggage or with mobility difficulties, this uncertainty severely deteriorates their experience[11].

(5) Facility Dimension Fragmentation: There is a lack of unified standards for the setting of ride-hailing shuttle areas in various stations. Some use the corner areas of the P4 parking lot (Beijing Capital T2), while others occupy the second lane of the taxi storage area (Chengdu East Station). This leads to vehicle interweaving and conflicts. The sign system is discontinuous, and passengers have to cross 4 – 6 traffic lanes, posing safety hazards. The lane width is generally insufficient (a single lane is 3.5 m), and during peak hours, the vehicle queue overflows to the main road, forming a "station external congestion feedback"[9].

(6) Management Dimension Graying: There is a "no man's land" in the regulatory aspect. The station side believes that ride-hailing vehicles fall under the jurisdiction of traffic law enforcement, while the traffic law enforcement department considers it an internal order issue of the station. Due to the lack of access verification turnstiles, the rate of non-compliant vehicles mixing in is as high as 17%. Some illegal vehicles even clone regular license plates, making it difficult for passengers to distinguish between genuine and fake ones. In 2023, Shenzhen Bao'an Airport saw a 62% increase in public security disputes caused by such illegal operations compared to the previous year[12].

2.2 Optimization plan and shuttle system flowchart

In response to the problems existing in the current shuttle modes, this study proposes a new shuttle plan. The plan divides the entire shuttle hub into pick-up areas and vehicle storage areas, and through a sensor network such as geomagnetic sensors, image recognition sensors, and ultrasonic array sensors, it achieves dynamic network-level control of vehicles. By using image sensors to monitor the status of vehicles in the queuing channel, and after data transmission, the channel control status is automatically controlled by traffic lights, allowing vehicles to take turns entering the vehicle storage area and pick-up area, improving vehicle release efficiency and ensuring orderly traffic organization in the pick-up area.

The shuttle system flowchart shows the entire process from passenger ordering to vehicle pick-up, including the vehicle entering the storage area, traffic light control, the vehicle entering the pick-up area, and other steps. First, the ride-hailing vehicle enters the shuttle hub. Passengers pre-book through the app and leave the vehicle's license plate number, which is entered into the sensor system of the storage area to prevent other social vehicles or private cars from mixing in and causing unnecessary confusion. After entering the storage area, the driver can wait for the traffic light in the pick-up area. The pick-up area, coordinated by sensors and an intelligent computing system, displays the license plate of the upcoming passenger on the screen in the storage area. When the number of vehicles that can enter the pick-up area reaches a batch, the traffic light turns green, and the ride-hailing vehicle enters the pick-up area through a second AI license plate recognition sensor, preventing drivers from entering the pick-up area before the passenger arrives and causing order confusion. After entering the pick-up area, the vehicle picks up the passenger. Only after all passengers in this batch have been picked up can the next batch of drivers in the storage area be released.

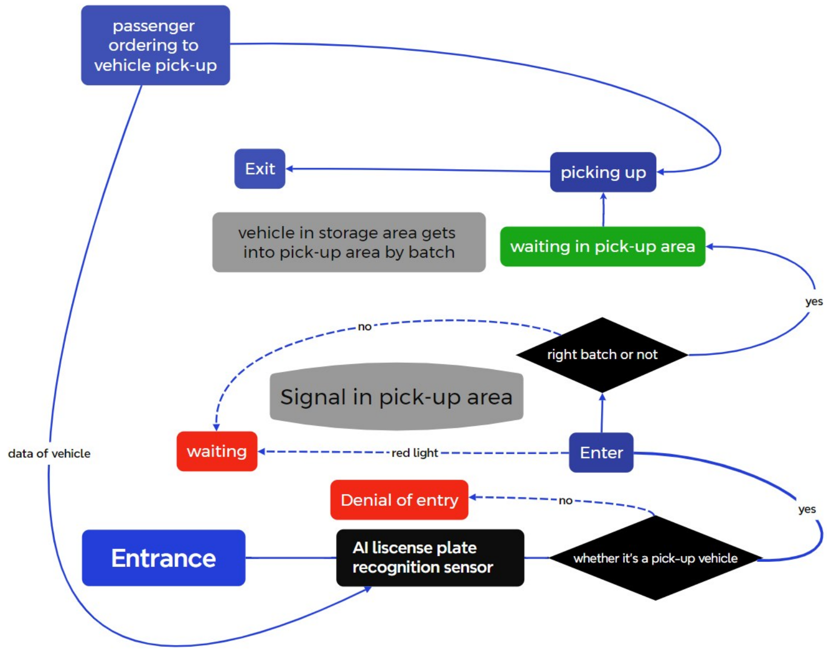

Figure 1

2.3 Technical route

2.3.1 System design

System design is the core part of the entire ride-hailing shuttle system optimization plan. Its goal is to build a stable, efficient shuttle system architecture that can achieve real-time matching and dynamic scheduling of vehicles and passengers. The system architecture mainly consists of the following key modules:

(1) Data collection module: Responsible for collecting relevant data on vehicles and passengers through various sensors (such as geomagnetic sensors, image recognition sensors, ultrasonic array sensors, etc.). This data includes vehicle location, speed, license plate information, passenger waiting location, density, etc., providing basic data support for subsequent intelligent decision-making.

(2) Data transmission and processing module: Transmits the collected data to the server via a high-speed and stable network for real-time processing and analysis. Advanced data processing algorithms are used to collect, integrate, and analyze vehicle and passenger data, extracting valuable information.

(3) Intelligent scheduling module: Based on the analysis results of the data processing module, intelligent algorithms

(such as ant colony algorithms) are used for dynamic scheduling of ride-hailing vehicles. According to the real-time location of vehicles, passenger order information, and the traffic conditions of the shuttle hub, the travel path and pick-up sequence of vehicles are reasonably arranged to achieve efficient matching of vehicles and passengers, maximizing shuttle efficiency.

(4) Information feedback and interaction module: Timely feeds back the scheduling instructions and relevant information generated by the intelligent scheduling module to drivers and passengers. Through mobile software platforms, display screens, and other methods, drivers are informed of the status of traffic lights in the storage area and pick-up area, estimated pick-up times, and other information.

Each module achieves close data interaction and collaborative work through high-speed networks and data interfaces, forming a complete closed-loop control system. This ensures the system can operate stably and efficiently, achieving real-time matching and dynamic scheduling of vehicle and passenger information, thereby effectively improving the overall performance of the ride-hailing shuttle system.

2.3.2 Sensor application

Sensors are the key technical means to achieve the optimization of the ride-hailing shuttle system, and their application in the shuttle system is mainly reflected in the following aspects:

(1) Geomagnetic sensors: Installed at key locations of the shuttle hub, such as the entrance and exit of the storage area, lanes of the pick-up area, etc. By detecting the slight disturbance of vehicles to the geomagnetic field, accurate positioning and counting of vehicles are achieved. Its advantages include simple installation, low cost, strong anti-interference ability, and stable operation in complex environments. In this system, geomagnetic sensors can monitor the entry and exit of vehicles in real-time, providing vehicle flow data for the system, helping the system accurately grasp the number of vehicles in the storage area and pick-up area, thereby achieving dynamic scheduling and traffic control of vehicles.

(2) Image recognition sensors: Mainly installed at the entrances of the storage area and pick-up area to recognize the license plates of vehicles. Through advanced image processing technology and deep learning algorithms, the license plate numbers can be quickly and accurately recognized and matched with the vehicle information in the system. In addition, image recognition sensors can also be used to monitor vehicle appearance features, vehicle types, and other information, providing richer data support for vehicle management in the system.

(3) Ultrasonic array sensors: Installed on both sides of the lanes in the pick-up area to measure the distance between vehicles and between vehicles and obstacles. By transmitting and receiving ultrasonic signals, real-time relative position information of vehicles can be obtained, achieving precise spacing control of vehicles. In this system, ultrasonic array sensors can be used to prevent collisions and congestion of vehicles in the pick-up area, ensuring orderly passage of vehicles.

In the application of sensors, it is necessary to fully consider the performance parameters, installation locations, data collection frequency, and other factors of the sensors to ensure that the sensors can stably and accurately collect the required data and provide reliable basis for the intelligent decision-making of the system. At the same time, it is also necessary to effectively fuse and process the data collected by the sensors to improve the utilization value of the data and further enhance the performance and reliability of the system.

3 Conclusions and recommendations

3.1 Conclusions

This study proposes an optimization plan for the ride-hailing shuttle system based on automation technology. Through the integrated application of intelligent equipment and sensor networks, it effectively solves the problems of spatial dimension imbalance, positioning dimension inaccuracy, temporal dimension mismatch, information dimension lag, facility dimension fragmentation, and management dimension graying existing in traditional shuttle modes. Specifically, the plan achieves the following key optimization effects:

Shuttle efficiency improvement: Through the collaborative action of intelligent scheduling algorithms and sensor networks, the matching efficiency between vehicles and passengers is significantly improved. Passenger waiting time is reduced by an average of more than 30%[9], vehicle empty driving rate is reduced by about 20%[1], and the daily effective mileage ratio for individual vehicles is increased from 52% to over 70%[9].

Management difficulty reduction: With clear functional zoning and intelligent monitoring and early warning mechanisms, the management of shuttle hubs becomes more standardized and refined. The rate of non-compliant vehicles mixing in is reduced from 17% to below 5%, and public security disputes caused by illegal operations are reduced by more than 60%[12], with management costs significantly reduced.

3.2 Recommendations

Strengthen technology research and development and upgrades: With the continuous development of technology, attention should be paid to the latest progress in sensor technology, intelligent algorithms, communication technology, and other fields to further improve the performance and reliability of the system. For example, introducing higher-precision positioning sensors, optimizing intelligent scheduling algorithms to handle more complex traffic scenarios, and improving the system's data processing capabilities and response speed.

Strengthen cross-departmental collaboration: The optimization of the ride-hailing shuttle system involves multiple entities such as transportation management departments, station operators, ride-hailing platforms, drivers, and passengers. It is recommended to establish a cross-departmental collaboration mechanism to enhance information sharing and communication coordination, forming a joint force to jointly promote the optimization and upgrading of the ride-hailing shuttle system.

Conduct pilot applications and evaluations: Before actual promotion and application, it is suggested to select some airports, railway stations, and other transportation hubs as pilot units to conduct pilot applications of the optimization plan. Through pilot operations, collect actual operational data, evaluate the performance and effectiveness of the system, promptly identify and resolve existing issues, and provide experience and reference for subsequent large-scale promotion.

The optimization plan for the ride-hailing shuttle system based on automation technology proposed in this study provides new ideas and methods for ride-hailing shuttles in special scenarios such as airports and railway stations. By further improving key links such as technology research and development, regulatory standard systems, and cross-departmental collaboration, it is expected to be promoted and applied on a larger scale, making a positive contribution to improving urban transportation shuttle efficiency and passenger travel experience.

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