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Research Article

Investigating Evaluation Indicators of Intelligent Vehicle Sharing Based on Operation Efficiency: A Case Study in Xiong'an New Area, China

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Under the background of implementing green travel in response to the national energy conservation and emission reduction policy, the concept of shared travel as a new transportation mode has been promoted. This paper aims at providing a more scientific and quantitative method to explore the shared travel traffic mode and evaluating efficiency with data mining technology. Based on the analysis of the evaluation index system of the existing intelligent shared mobility, this paper firstly points out some issues in reflecting the operation efficiency of a specific shared mobility service. In order to find out the characteristics of passenger flow and propose recommend indicators, this study presents a detail analysis using data in Xiong'an new area from September 2020 to September 2021. Then, this paper proposes a time-series algorithm to identify ridesharing behavior of demand responsive (DR) bus and to recommend indicators on operation efficiency considering capacity, turnover, and time. Moreover, the definition of indicators and calculation of case study are carried out. Results show that the utilization rate of vehicle seat for DR bus was increased by 1.6–2.5 times, and the turnover efficiency was increased by about 2 times compared to private cars and taxi. In general, this paper quantitatively describes the improvement of operation efficiency brought by bus sharing, which shows that this kind of shared mobility has the attributes of public transport in a certain sense. Also, this paper shows that the above indicators are quantifiable and comparable, which is a useful supplement to the existing evaluation index system.

1. Introduction

Recently, variety of travel services such as online ride-hailing, carpooling, car-sharing rental, and bicycle sharing have constantly emerged, such a travelling mode between traditional intensification and privatization not only enriches people's travel choices, but also becomes an important carrier for the landing of intelligent transportation technology [1]. Meanwhile, these new modes of travel have good prospects in reducing carbon emissions and alleviating congestion since vehicle resources, time resources, and road resources are shared through various ways, which has attracted extensive attention from the government, academia, and various commercial organizations. Both disagreements and consensus exist in terms of how to find a sustainable business model, whether it can be included in the broader context of public transport, and what attitude the government should regulate or encourage. Regarding the issue above, it is necessary to establish objective and complete indicators evaluation system to define these new travel modes and distinguish it from traditional public transport and private ones. However, objective evaluation of various travel services provided by different service providers is a complex and long-term work for the reason that sharing mobility is in primary state of development, differences in the positions of the various institutions themselves and differences among cities.

Sharing economy has attracted the most sharply increased attention throughout the world in recent years. Shared mobility is an important part of the comprehensive urban transportation system. It refers to a new mode of transportation in which people share their cars with others without owning the ownership of the vehicle and pay corresponding usage fees according to their own travel requirements [2, 3]. In relation to shared mobility, numerous studies focus on bicycle sharing [4], vehicle sharing [5], and carpooling [6]. In order to improve the service level and customer satisfaction, Liu et al. [7] identified five main factors, i.e., convenience and flexibility, operation service, economic cost, design and layout, and management specification, which affecting bicycle sharing operations by using the Multi-Criteria Decision-Making (MCDM) approach. Maeng et al. [8] analyzed consumer preference and willingness to pay for a shared autonomous vehicles service, focusing on the automation level of the shared vehicle and liability for an accident. Li et al. [9] measured the traffic benefits attributed to carpooling by using integer program and found the total trip volumes and commuter trips in peak hours were both reduced when adopting carpooling for travelling. With the rapidly development of big data in transportation, machine learning and data mining approach were also widely used in this field [10–12].

In relation to vehicle operating efficiency, most of studies focus on time efficiency [13], spatial efficiency [14], and energy efficiency [15]. Farhan et al. [16] explored the impact of ridesharing on operational efficiency of shared autonomous electric vehicle fleet by using tabu search and found that service rate and system savings were significantly improved, whereas the fleet size and the number of charging stations were decreased in the context of ridesharing operations. Fang et al. [17] defined a space-time use efficiency metric on the basis of trajectories on road segments and intersections and solve three optimal objectives including minimizing average evacuation time, the overall length traveled, and maximizing space-time use efficiency by using two-tier hybrid multi-objective optimization algorithm. Bai et al. [18] analyzed the operational characteristic of taxi system by using data envelopment analysis (DEA) method and evaluates its operational efficiency from the economic perspective considering the indicators of fuel cost.

In relation to evaluation indicators of shared mobility, previous studies focus on the evaluation of environment-, public- and individual user-interest-related effects of shared mobility. In order to assess the sharing effects on urban transport sustainability, Tao et al. [19] established models of bike-sharing resource demand and greenhouse gas emission, user transport time and cost, and roadside parking space demand allocated in the functional unit of transporting one passenger for one kilometer. Wang et al. [20] focused on car sharing and private ones, and proposed evaluation indicator system from three dimensions (time, spatial, and decision-making) for their usage pattern comparison, which included time distribution pattern, daily/trip driving range, mileage, speed, charging duration, and so on.

As for vehicle sharing in China, the Evaluation Index of Intelligent Shared Travel compiled by China Association of Automotive Engineering provides the evaluation indicators of intelligent shared mobility, aiming to evaluate the development of the industry and the operation status of enterprises. In general, the major index of vehicle sharing management and 26 subindexes including the proportion of shared passengers, penetration rate of car-sharing travel, average daily passenger volume, and per capita travel cost. In the existing index system, vehicle sharing evaluation is carried out from four aspects including the people (share of passengers, average daily passenger volume, transfer time), the vehicle (operating vehicle density, operating a car/a number, the car service pipe), road (crew mileage, travel car sharing permeability), and environment (the car service pipe, the qualified rate of vehicles cleans and tidy, car service). Additionally, index for vehicle intelligence level (onboard terminal installation rate) and drivers' behavior (illegal rate of road traffic) are also involved in the evaluation system, which facilitate the variety perspectives of evaluation and the data is highly measurable. However, most of the existing index systems are common indicators of shared mobility and traditional transportation modes, which cannot highlight the core value of "sharing" and lack of indicators centered on operation efficiency, which cannot reflect the benefits brought by sharing. Moreover, the types of shared mobility have not been differentiated in the index system, in which ridesharing behavior online ride-hailing and car-sharing rental have different characteristics in the evaluation of shared mobility, and uniform index would ignore the essential characteristics of them [21]. Therefore, further mining of indicators is helpful to enhance the applicability of index evaluation.

Chinese Society of Automotive Engineering, as an authoritative industry organization, compiled the "Evaluation Index of Intelligent Shared Travel for Cars" with relevant unions, and makes a useful attempt in the evaluation of vehicle sharing. As a member of the Shared Travel Committee of China Society of Automotive Engineering and a planner and builder of Xiong'an New Area, the author tried to investigate the evaluation indicators of "Evaluation Index of Intelligent Shared Travel for Cars" based on operation efficiency by using the actual data from demand responsive (DR) bus in Xiong'an. Specifically, the evaluation method proposed by this study focuses on the sharing behavior itself instead of traditional common indicators. From this point of view, this study can help identify the specific benefits which can be brought by ridesharing behavior in a shared transportation mode service. Therefore, it can help the operator to better analyze the proportion of ridesharing behavior in the shared transportation mode and quantify the benefits it brings, including time, road network load, and even carbon emission efficiency. At the decision-making level, these quantitative indicators can also help to have a clearer understanding of the operation status and sustainable development of this specific traffic mode. Under the complete and high-quality data provided by Xiong'an new area, it not only strongly supports the demonstration of this study at the theoretical level, but also has scientific guiding significance at the practical level to operating enterprise.

2. Data Process

2.1. Data Source. In order to improve the proportion of green transportation and public transportation trips, the

Master Plan of Xiong'an New Area, Hebei Province in China clearly proposes the establishment of a demand-responsive public transportation system, in which models with 7 to 10 seats are adopted and the route is generated intelligently based on dynamic demand.

DR bus in Xiong'an is a new operation pattern of bus and also an important part of the transportation system of starting area in Xiong'an. The characteristic of ridesharing for DR bus fully conforms to the development concept of Xiong'an transportation: "reduce traffic congestion, easy to use, providing high-quality bus services." For the reason that Xiong'an is mainly in the state of urban development and construction, the capital's population has yet to be imported on a large scale to form a concentrated bus passenger flow corridor; DR bus is operating in Rongcheng County and Rongdong group as is depicted in Figure 1. Moreover, trial operation of DR bus began in September 2020 and official operation in October at the same year, and the one-year anniversary was completed in September 2021.

The operation concept of DR bus in Xiong'an is "semiopen, customization, site-intensive, sharing," and the supplement of vehicle is elastic, restricted by operation rules of fixed site uncertain route. Ridesharing behavior can be achieved, such as commuting, once duplicated routes existed in passengers' trips. Users place orders using the APP "Xiongan Xing" and accept the ridesharing mode by default, the vehicles will be sent in the mode of "one car to several people" and "single order along the road." Among them, fixed sites mean that the location on and off the bus is fixed. Uncertain route means delivering passengers by the route with shortest travelling time. Generally, DR bus outperforms conventional public traffic or taxi by the flexible operation rules and high efficiency. Compared to ridesharing pattern of online ride-hailing, DR bus is more organized in terms of avoiding the problem that too large detour distance for some passengers of different orders. Take "one bus, three orders, four passengers, four stops" as an example, the way that DR bus operates is depicted as in Figure 2:

In the context of bus sharing, this paper uses more than 300,000 actual data of flexible bus system operation in Xiong'an New Area from October 2020 to September 2021 to master the rules of vehicle operation, study the user's travel behavior, and improve the operation efficiency of the system [22]. Moreover, this paper constructs operation management database for selecting evaluation indicators on shared mobility and analyzing operation characteristics based on efficiency, which is discussed in the next section.

2.2. Data Variable Selection. In this paper, the operation management database was established based on the actual data above by using Pandas based on Python. These data excluded abnormal data, such as imperfect records and clear errors. According to the characteristics of shared mobility in DR bus, the operation management database covers four aspects of order attributes, user attributes, vehicle attributes, and site attributes, which is summarized in Table 1. Some variables can be acquired by discretization and data cleaning, such as number of passengers, mileages, and number of sites, while others including active user, commuting user, and average daily capacity should be acquired through data matching and extraction based on Python.

3. Methodology

3.1. Identification of Bus Sharing Based on Time-Series Algorithm. Identifying ridesharing behavior of order is the basis of database field supplement and the core of indicator's evaluation. This paper proposes a time-series algorithm for ridesharing behavior identification in DR bus service, in which the process is shown in Figure 3. The order data were arranged in order of the pickup time of passenger from early to late in order to facilitate processing. Two user orders form a single bus sharing order once the travelling time of two adjacent orders overlaps in the same vehicle. Therefore, the user's ridesharing behavior is identified, and the form of the sharing order is analyzed by traversing the order successively according to the process in Figure 3, for example, two users' orders or multiusers orders form a single sharing order.

3.2. Evaluation Indicators of Intelligent Vehicle Sharing Based on Operation Efficiency

3.2.1. Principles for Selecting Indicators. It is difficult to quantify the benefits generated by the specific ridesharing behavior only through the DR bus order data. Therefore, after the identification of ride in behavior, it is essential to put forward the calculation indicators for the specific orders with ridesharing behavior. In the process of a trip, both time efficiency and space utility are important factors considered by travelers and even the entire transportation system. Based on the actual operation of DR bus sharing in Xiong'an New Area, this section illustrates the selection principles of evaluation indicators from the following three aspects.

(a) Improving capacity. Currently, the average daily morning peak demand for DR bus sharing is 356 people. Due to the differences in the average number of passengers carried among various trip modes, the vehicle demand varies. Specifically, 20–40 DR buses (5-seat car) are required for ridesharing mode, 297 cars for single private mode, and 238 cars for hybrid mode of private and taxi. In comparison, DR bus sharing can reduce the size of vehicles by 6–7 times, and the utilization efficiency of seats is significantly improved, which has an immediate effect on alleviating the problem of urban parking difficulty by reducing parking demand.

(b) Increasing turnover. Based on users' morning peak travel demand (492 km/day) and sharing service usage, the mode of DR bus sharing can complete the turnover of 732 people vehicle kilometers in the average daily morning peak for the entire transportation system, and the actual turnover is 140 km more than the nominal turnover, significantly reducing the traffic load of network during morning peak time.

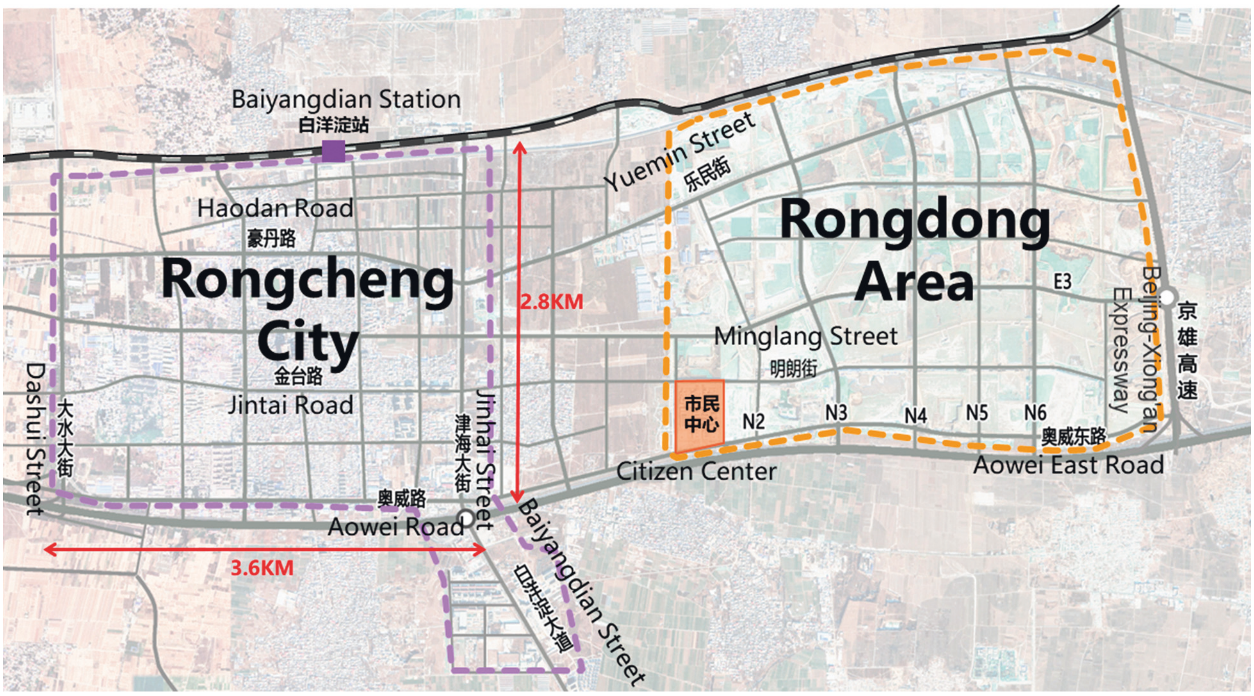


Figure 1: Operation area of Xiong'an DR bus.

(c) Increasing time efficiency. According to the calculation and analysis, the whole process of a bus sharing trip takes about 22~28 min on average, which is more efficient than that of the traditional bus (35~41 min). In addition, due to the sharing behavior, the actual operating time of the vehicle in the whole process is significantly reduced compared with the nominal running time of each single trip, saving the time cost of the vehicle.

Based on the above analysis, this paper considers the three factors of transport capacity, turnover and time, and proposed the evaluation indicators of intelligent shared mobility for vehicles with operation efficiency as the core.

3.2.2. Definition of Evaluation Indicators

(1) Recommended Indicator 1. Seat Utilization Efficiency (SUE). In a ride-sharing trip, SUE is the ratio of the actual number of seats used by passengers to the vehicle seat supply, which is shown in the following formula:

$$\alpha = \frac{\sum_{1}^{i} n_i t_n}{NT}, \quad (1)$$

where i represents the number of single orders in a ridesharing, n_i represents the number of passengers of each single order in a ridesharing, t_n represents the number of passengers of each single order in a ridesharing, N represents the actual number of seats supplied in a vehicle, T represents the total time of a ridesharing. As shown in Figure 4, SUE is calculated by taking two single rides as one ridesharing in a 5-seat car (set the number of passengers per each single ride as 1) as an example. The calculation process of SUE in this example is shown in formula (2):

$$\alpha = \frac{1 \times 6\text{min} + 2 \times 6\text{min} + 1 \times 6\text{min}}{4 \times 18\text{min}} = 33.33\%. \quad (2)$$

(2) Recommended Indicator 2. Turnover Efficiency (TE). In a ride-sharing trip, TE is the ratio of the sum of the actual completion turnover of each single order to the nominal ridesharing completion turnover, which is shown in the following formula:

$$\beta = \frac{\sum_{1}^{k} n_k d_k}{D \sum_{1}^{k} n_k / k}, \quad (3)$$

where k represents the number of single orders in a ridesharing trip, n_k represents the passenger number of each single order, d_k represents the travel distance of each single order, D represents the distance of a ridesharing that the vehicle actually travels. As shown in Figure 5, TE is calculated by taking three single rides as one ridesharing in a 5-seat car (set the number of passengers per each single ride are 1, 1, 2, respectively) as an example. The calculation process of TE in this example is shown in the following formula:

$$\alpha = \frac{1 \times 4km + 1 \times 4km + 2 \times 5km}{8km \times 1 + 1 + 2/3} = 1.69. \quad (4)$$

(3) Recommended Indicator 3. Time Utilization Rate (TUR). In a ride-sharing trip, TUR is the ratio of the time reduced by the ridesharing behavior by each single order to the sum of the travel time of each single order, which is shown in the following formula:

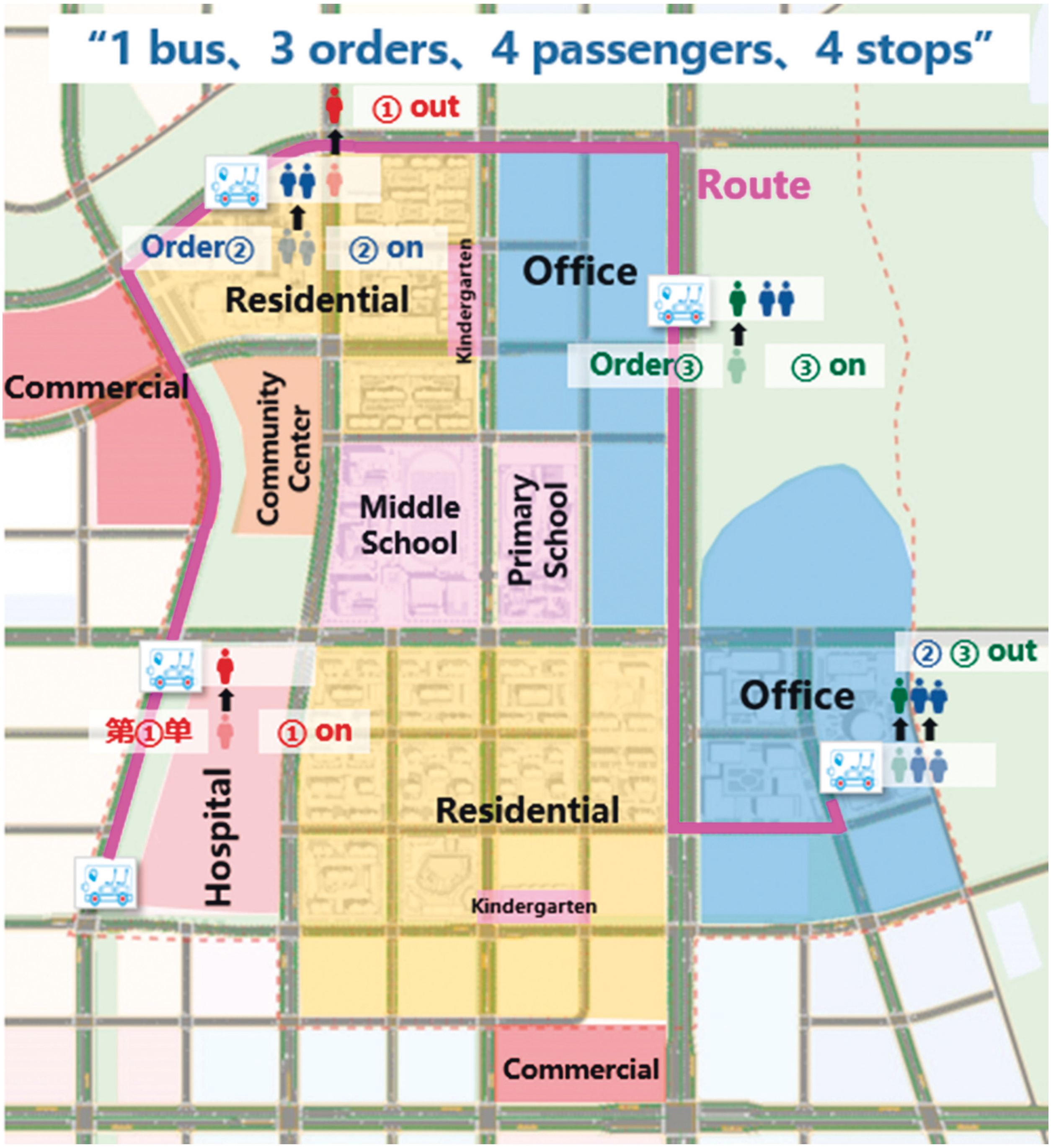


Figure 2: Example of DR bus sharing.

$$\gamma = \frac{\left(\sum_1^k t_k\right) - T}{\sum_1^k t_k} \times \frac{k}{k-1}, \quad (5)$$

where t_k represents the duration of each single order, the other variables have the same meaning as the above formula. As shown in Figure 6, TUR is calculated by taking three single rides as one ridesharing in a 5-seat car as an example. The calculation process of TUR in this example is shown in the following formula:

$$\gamma = \frac{(6\text{min} + 6\text{min} + 7\text{min} - 10\text{min})}{(6\text{min} + 6\text{min} + 7\text{min})} \times \frac{3}{3-1} = 71\%. \quad (6)$$

4. Results and Discussion

4.1. Overview of Bus Sharing Operation. In order to understand the operation of DR bus sharing in Xiong'an New Area, the data in Table 1 are calculated and analyzed as follows.

Table 1: Attributes of Xiong'an bus sharing dataset.

Attributes	Variable name	Variable description/example
Order attributes	ID	2010010####7704000000
	Orders	26209 (September, 2021)
	Appointment	2020/10/1 6:48:42
	Sending time	2020/10/1 6:48:45
	Pick-up time	2020/10/1 6:51:00
	Get-off time	2020/10/1 6:58:15
	Waiting time	154 (s)
	Orders duration	416 (s)
	Order cost	4.8 (yuan)
	Ride share or not*	1 = yes; 0 = no
User attributes	Contacts	Li#yuan
	Phone number of contacts	198####6900
	Number of passengers	Number of passengers on the current order
	Active user*	Monthly car use records
	Commuting user*	Daily car use records
Vehicle attributes	License number	Ji F####24
	Driver	Li#xiang
	Phone number of driver	166####959
	Average daily capacity*	Orders/operating days
	Mileage	3.8 (km)
Sites attributes	Number of sites	120, dynamic adjustment according to passenger flow
	Layout of sites	200–600 m, not restricted by the minimum sites spacing

Notes:* Represents obtained by data matching and extraction.

In terms of users, the DR bus sharing in Xiongan New Area adopts the passenger whitelist system. It is mainly targeted at the staff of the area and those involved in planning and construction work. This research defines passengers with monthly usage records as active users, and the growth of users and orders is shown in Table 2. Take September 2021 as an example, the number of people on the whitelist reaches 12042, where 3554 active users and 26209 orders are contained, showing a significant increase in monthly operation data compared to the same period last year.

In terms of vehicles, Xiong'an New Area took 5-seat new energy car as the main type of DR bus sharing in the initial stage, and then 13-seat minibus was put into use in July 2021. The daily operation time of bus sharing is 5:00–23:00. Figure 7 shows the calculation results of the orders completed (average daily capacity) under the daily operation time of the current service. The results show that the fleet size of the bus has increased to 41, which is significantly higher than that in the initial operation stage. The average daily transport capacity is 20 ~ 30 orders and remains stable.

In terms of stations, since the operation of bus sharing in Xiongan New Area, the number of stations has increased from 93 to 123, covering main functional areas such as Rongcheng County, Rongdong Resettlement Area, and Rongxin Road Office Area. The distance between stations is about 200m to 600m, and can be flexibly set according to individual characteristics and demands. Besides, it is closely combined with the origin and destination points of trips, realizing door-to-door service (Figure 8).

4.2. Passenger Flow Characteristic and Service Analysis

4.2.1. Passenger Flow Characteristic. Passenger flow characteristic is an important basis for the operation analysis of public transport system, and improving service level is an important way to attract demands. During the first year of bus sharing operation, the Xiong'an bus sharing system makes statistical analysis of daily order volume based on the operation management database, and mines the service group, passenger distribution, and service level of the sharing transport mode.

At present, the main objects of Xiong'an bus sharing service are commuter and business travelers, thus the distribution of passenger flow changes periodically. In terms of the time distribution, the passenger volume is larger on weekdays and smaller on weekends, specifically, it is higher on Monday and Friday (Figure 9), which is consistent with the travel characteristics of commuter passenger flow. From the point of commuter traffic, weekday passenger flow shows an obvious "double peak" with large and concentrated passenger volume (Figure 10), which is mainly occurred in morning and evening peak. Flat peak is about half of peak passenger volume, and business traffic accounts for a main proportion. The passenger flow on weekends is small, showing a flat peak in the majority, and the passenger flow reaches the peak on Sunday evening (Figure 11). From the perspective of the spatial distribution, the production and attraction of the same station are close, and the main origin and destination points of passenger flow are office, residential, and hub land, which is consistent with the characteristics of travel destinations of commuters (Figure 12(a)). The stations with large passenger volume are Citizen Service Center, Baiyangdian Station, Aowei Tower, and Rongxin Road Office Area (Figure 12(b)).

4.2.2. Level of Service. Travel cost is an important factor affecting the quality of travel service, with cost and time as

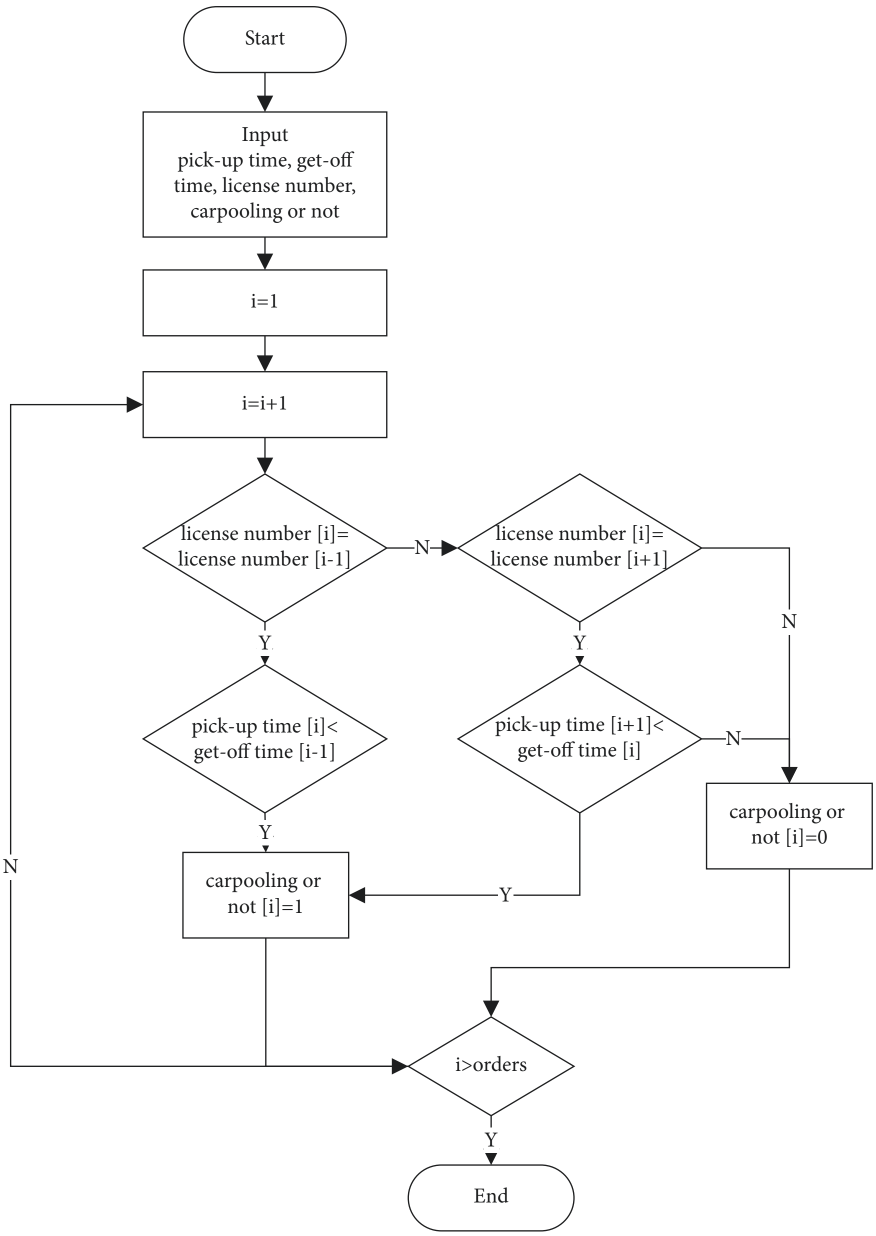


Figure 3: Flowchart of identifying ridesharing behavior of DR bus.

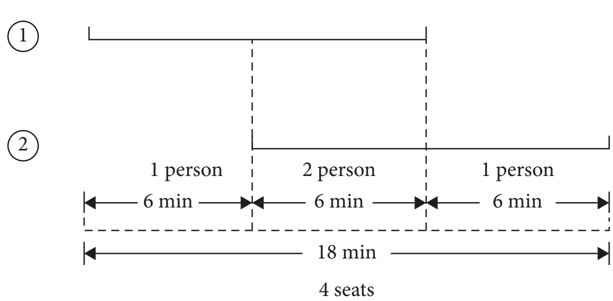


Figure 4: Recommended indicator 1: example of SUE.

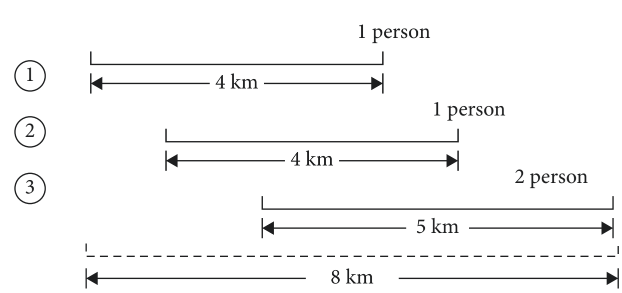


Figure 5: Recommended indicator 2: example of TUE.

the two main components. In terms of cost, compared with the traditional rule of fare by mileage, the price of DR bus has more advantages. As shown in Table 3, the shared bus is charge by the number of people, and discounts are given to the orders of multiple people sharing the trip. The discount is based on the longest distance of sharing, excluding the

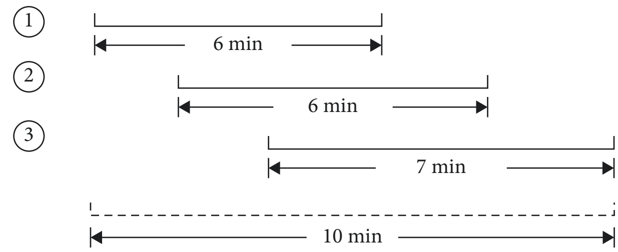


Figure 6: Recommended indicator 3: example of TUR.

Table 2: Growth of users and orders.

	Whitelist users	Active users	Orders
Oct. 2021	5386	1110	9084
Sept. 2021	12042	3554	26209
Annual growth	125%	220%	190%

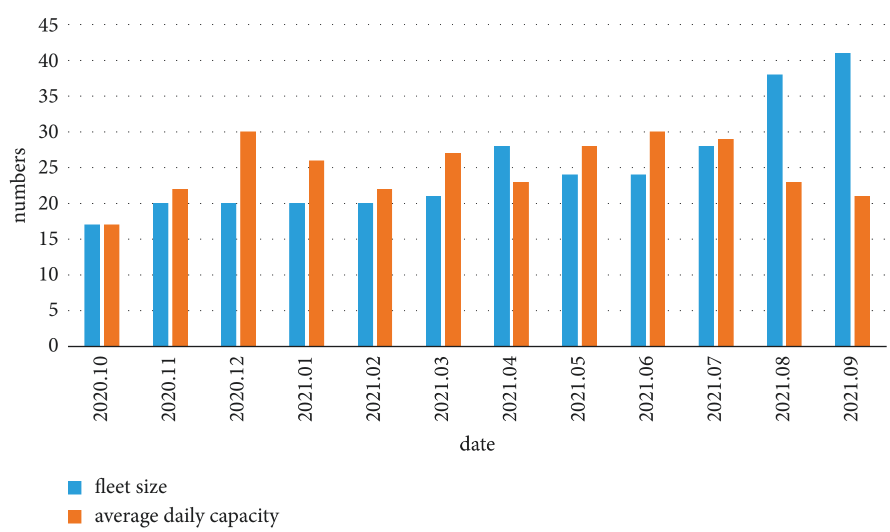


Figure 7: Operation situation of Xiong'an bus sharing.

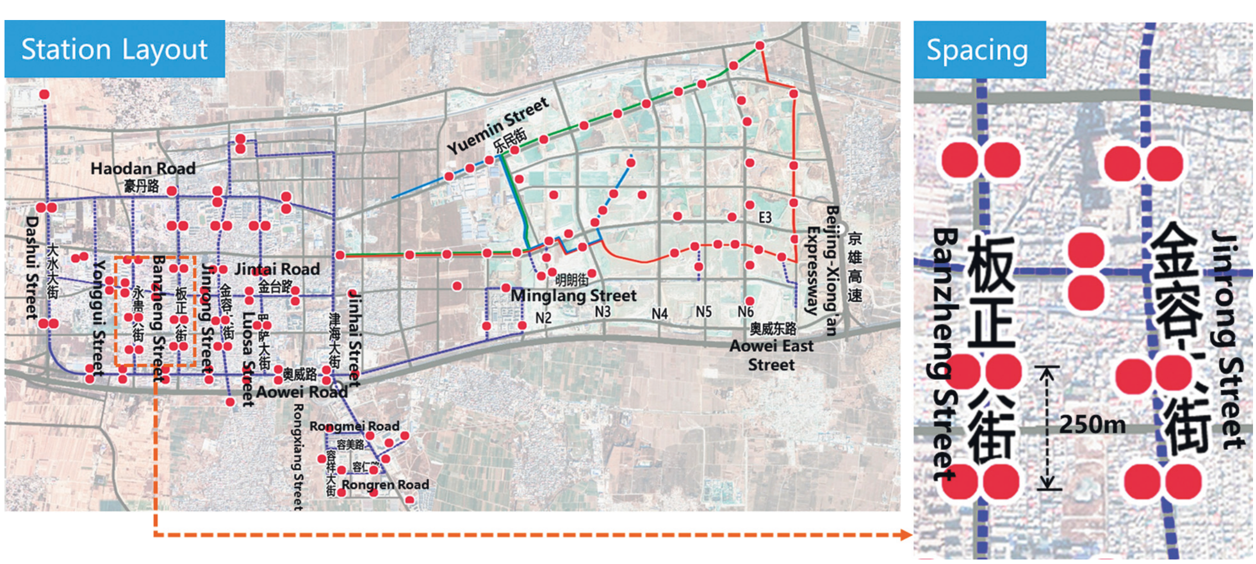


Figure 8: Station layout of Xiong'an bus sharing service.

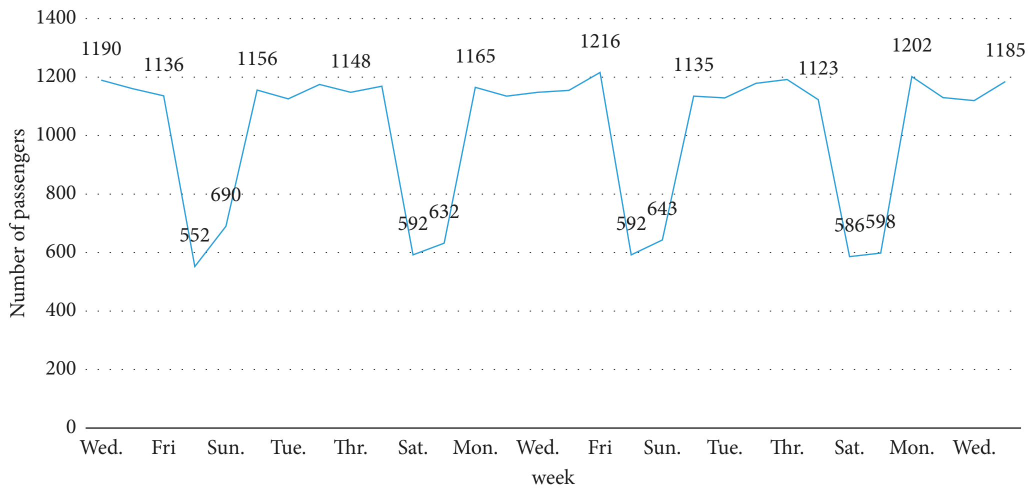


Figure 9: Passenger flow distribution of September 2021.

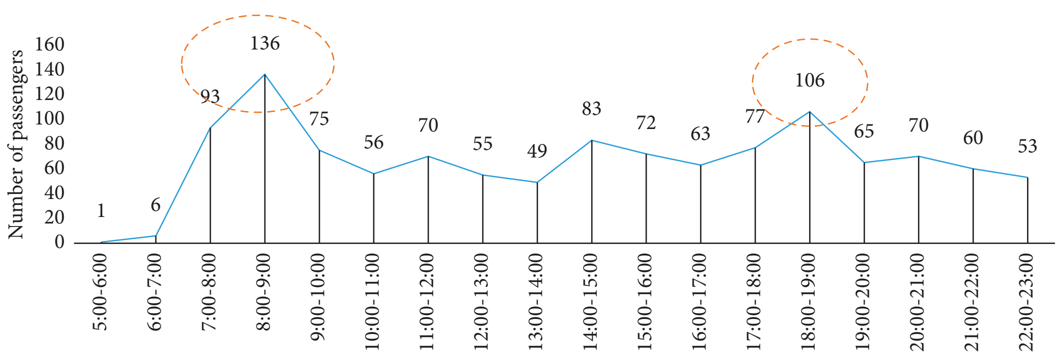


Figure 10: Passenger flow distribution of one workday in September 2021.

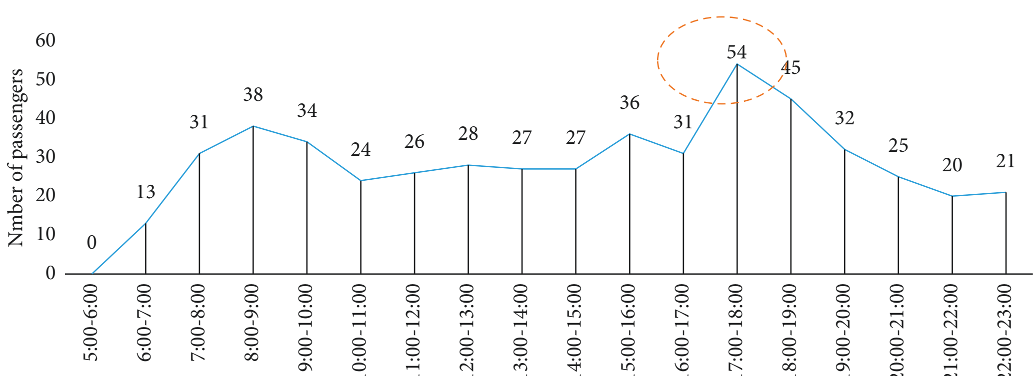
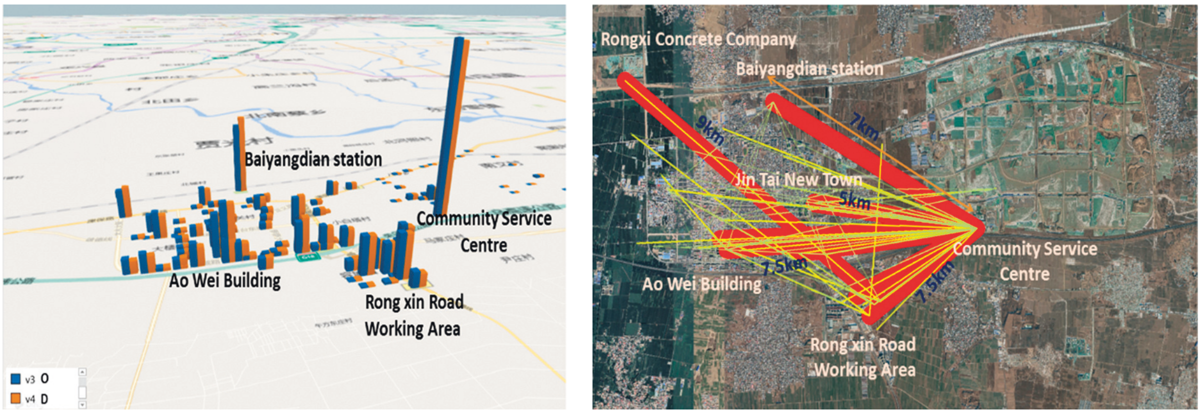


Figure 11: Passenger flow distribution of one weekend in September 2021.

situation of sharing different orders at the same time. Showing the prices of bus sharing and taxi in different travel mileage (Figure 13), a comparison of prices can be concluded: the price of bus sharing is about 0.4–0.7 times that of taxi, especially when there are 1–2 people per order, the price of bus sharing is only 50% of that of taxi.

In terms of travel time, under the same travel distance, the travel time of DR bus is close to that of private car and taxi. Compared with the traditional bus, it has more advantages. According to the current statistical data of bus sharing trips in Xiong'an, taking the average travel distance of 4.2 km as an example, the "door-to-door" travel time of shared bus, traditional bus, private car, and taxi are calculated. Private cars and taxis are point-to-point travel modes with less time between them. The travel process of traditional bus is similar to that of shared bus. The connection between the station and the travel destination mainly depends on walking. The walking distance of traditional bus stations is about 300 to 500 meters, while that of shared bus is only about 100 to 200 meters, which means walking distance is



(a)

(b)

Figure 12: Spatial distribution of passenger flow. (a) OD bar chart, (b) OD distribution.

Table 3: Fare rule of bus sharing and taxi.

Price		Discount rate for multi-person			
Base fare (within 3 km)	Mileage fee (over 3 km)	1	2	3	≥4
4 RMB	1 RMB/km	1	0.6	0.5	0.4
	Comparison with taxi				
Base fare (within 2 km)	Mileage fee (over 2 km)	—	—	—	—
8 RMB	2.1 RMB/km	—	—	—	—

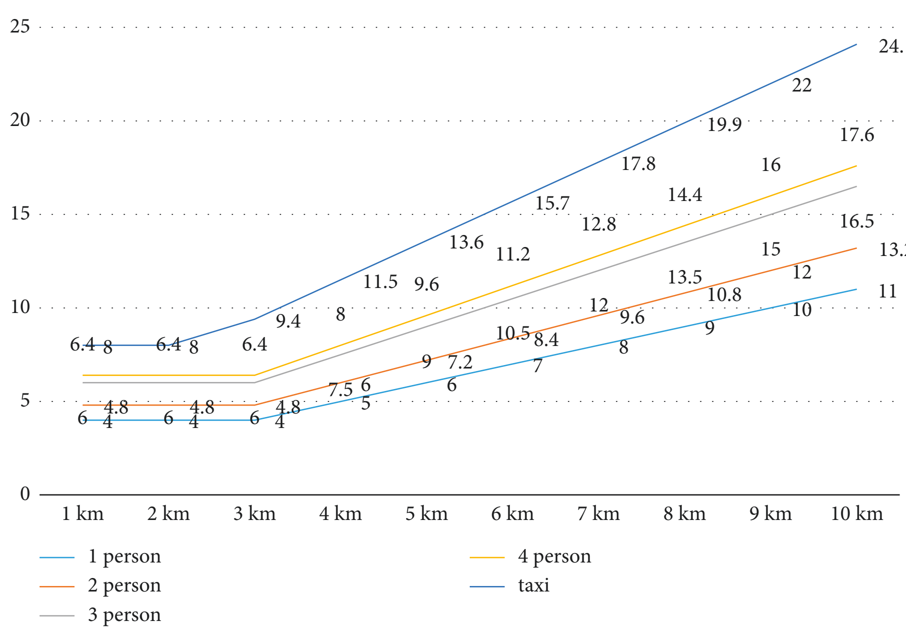


Figure 13: Price comparison of different mileage between bus sharing and taxi.

significantly reduced. At the same time, the bus sharing provides point-to-point service, and passengers do not need to transfer. As shown in Figure 14, the whole process of bus sharing travel takes about 22–28 min, which is slightly lower than private cars (15 min) or taxis (18 min). In addition, compared with 35~41 minutes of traditional bus mode, bus sharing mode has better service level.

4.3. Evaluation Indicators Validation. In order to validate the applicability of the recommended indicators, the DR bus operational data of Xiong'an New Area from October 2020 to September 2021 is introduced as a calculation case study. Based on the shared mobility proposed in this paper, this section calculates the above recommended indicators which reflect operational efficiency, taking bus sharing and taxi

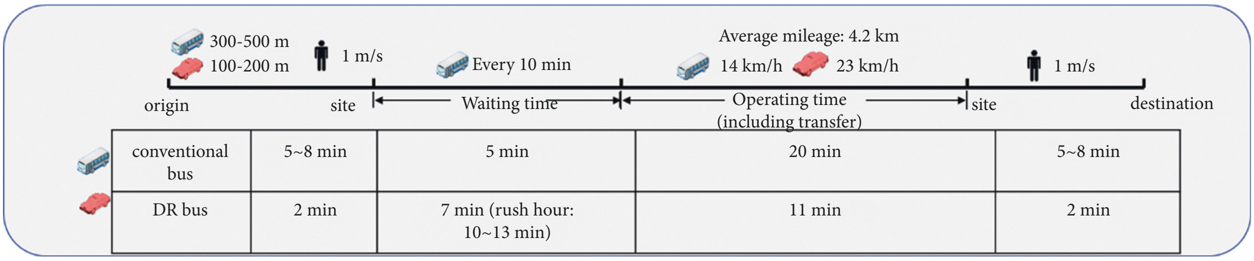


Figure 14: "door-to-door" operation of traditional bus mode and shared bus mode.

Table 4: Ridesharing order and composition analysis.

	Ridesharing	2 single orders	3 single orders	4 single orders	5 or more single orders
Whole year	28601	73%	20%	6%	1%
Morning peak	8013	61%	26%	11%	2%
Evening peak	5657	76%	19%	5%	0.2%
Flat peak	14931	79%	17%	4%	0.4%

(private car) as the research objects. Furthermore, the results also indicate the benefits of the mode of bus sharing on the entire transportation system.

The determination of ridesharing behavior and analysis of the composition of one ridesharing are the basis of calculating the recommended indicators. In this paper, the time-series algorithm was used to identify the ridesharing behavior of 189029 single DR bus orders, and 28601 orders with ridesharing behavior were finally obtained, which accounted for 29.30% of the total amount. For ridesharing orders, the main form of ridesharing consists of 2–3 single orders, accounting for about 93%; In addition, ridesharing that consists of more single orders seems to occur in the morning peak more likely. The number and composition of ridesharing are shown in Table 4:

Table 5 calculates the SUE, TE, and TUR of the bus sharing in Xiong'an New Area during the early peak hours of the whole year, and makes a comparison with the traditional transportation mode. The results show that compared with the traditional modes of private cars and taxis, DR buses have obvious advantages in terms of capacity (SUE), turnover (TE), and time (TUR).

From the above calculation results and discussion, DR bus has showed advantages over other traffic modes due to its ridesharing behaviors. At the level of the whole transportation system, it also makes a significance from aspects of congestion, network load, and carbon emission benefits. In terms of congestion, under the road network length of about 33.5 km in Rongcheng, DR bus can save 139.93 km∗vehicle in the morning peak, which has played an essential role in congestion problem. In terms of traffic network load, Table 6 shows the vehicle fleet size when different transportation modes serve the morning peak travel demand. The results show that under the same demand, the fleet size of 20–40 DR buses can significantly alleviate the traffic load of the road network compared with other traffic modes. Furthermore, compared with traditional cars and new electric vehicles, DR bus can save 29.98 t and 18.97 t carbon emissions, respectively, which strongly responds to and supports the green travel and national "double carbon" policy.

Table 5: Calculation results of bus sharing recommended indicators in Xiong'an New Area.

	SUE (%)	TE	TUR (%)
Whole year	57	1.93	78
Morning peak	60	2.19	81
Comparison with traditional transport modes			
Private car	24	1	0
Taxi	35	1	0

Table 6: Vehicle fleet size of different transportation modes to serve the morning travel demand.

Transportation mode		Fleet size
DR bus		20–40
100% private car		297
Private car & taxi	50% private car	149
	50% private car	89

5. Conclusions

Through the analysis of the actual order data of DR bus sharing operation in Xiong'an New area, it is found that the operation efficiency can be improved, which shows the advantages of this kind of sharing mode compared with traditional private cars and taxis. In addition, this research also provides a certain public transport attribute, which provides a discussion basis for the subsequent policy formulation such as whether to include public transport management and whether to adopt government purchase services or franchising. Specifically, the main contribution of this study can be concluded as follows.

(a) This paper proposes a time-series algorithm for identifying ridesharing behaviors. Therefore, it helps better recognize and analyze the specific orders with ridesharing behaviors in transportation mode of DR bus.

(b) Based on the three aspects of capacity, turnover, and time, the paper introduces three indicators for evaluating efficiency of ridesharing behavior. SUE, TE, and TUR can better quantify the significance of ridesharing in DR bus service.

Furthermore, considering the relationship between DR bus operation and the whole transportation system, this paper illustrates the contribution of DR bus ridesharing to congestion, network load, and carbon emission. Based on the case calculation, a positive result is obtained. However, there are few limitations and expectation in this research. On the one hand, the algorithm of identifying ridesharing can be further optimized to meet the requirement of calculation efficiency when data amount increases. On the other hand, more diversified indicators can be also proposed to reflect the interaction between ridesharing behavior and other transportation modes or the whole transportation system. In future work, through the continuous tracking of various shared travel service products operated by Xiong'an New Area and other cities, we can further supplement the operation efficiency indicators such as green travel sharing rate of users and carbon reduction and congestion alleviation, further improve the evaluation system, and provide assistance for the standardized development of shared travel industry, urban public transport and green travel, as well as the realization of double carbon goals.

Data Availability

Some or all data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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