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Equalized Utilization Model of Regional Shared Parking Space

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Abstract: In view of the contradiction between dense parking demand and limited parking resources, according to the time-varying characteristics of parking demand of different building types in the city, a dual objective parking allocation model with the highest equilibrium degree of shared parking utilization and the minimum walking distance was established. The model defines the boundary constraints of the walking distance and the equilibrium utilization, weights the multi-objective function, and then uses the genetic algorithm tool to solve it. Taking Tangshan Second Hospital and its surrounding areas as an example, the basic data such as the total number of parking Spaces, parking demand and walking distance after parking in each parking lot were obtained. The simulation output of parking space utilization and parking allocation in the area was carried out by the simulation algorithm, and the feasibility of the model was verified. The results show that the model can be used to allocate shared parking Spaces in urban areas, which can effectively balance the utilization rate of parking lots in the region and alleviate the problem of uneven and inadequate parking resources utilization in the region.

Keywords: Traffic planning, Shared parking, Genetic algorithm, Balanced utilization of berths.

1. Introduction

In recent years, China's rapid economic development has led to an increasing popularity of motor vehicles, and according to the Ministry of Public Security, as of the end of March 2022, the number of motor vehicles in the country reached 402 million, including 307 million cars, and the contradiction between parking supply and demand has led to the increasingly serious problem of urban traffic congestion. Due to the limited land resources within cities and the long construction cycle of parking facilities, it is important to improve the utilization rate of existing parking resources in cities based on parking space sharing theory to alleviate the problem of urban parking difficulties.

Regarding the theory of parking space sharing, early scholars at home and abroad focused more on the feasibility of parking space sharing policy implementation and its impact on the existing land use planning and parking demand forecasting theories. In this regard, Ommeren [1] and Inga et al [2] analyzed the feasibility of implementing parking parking sharing schemes based on the spatial and temporal characteristics of parking use; Resha [3] proposed the problems and obstacles in the practical application of parking sharing through a survey of users, and proposed shared parking implementation regulations; JiangY et al [4] mainly focused on parking generation rate and parking search time, etc. Xue Xingjian et al [5] proposed a parking demand prediction method based on parking sharing in new urban areas; Su Jing et al [6] explored the impact of the change in the proportion of parking demand on the scale of parking supply and sharing utility in mixed land use under the parking sharing mechanism.

With the gradual development of sharing theory, scholars began to focus on the efficiency of shared parking and the interests of demanders. Guo et al [7] used simulation to construct a parking buyback model with the goal of maximizing the interests of parking demanders to obtain the optimal parking use strategy under the parking time constraint; Pengfei Wang et al [8] constructed a theoretical model of shared parking allocation, pricing and revenue based on the auction mechanism; Shao et al [9] constructed a binary integer planning model for shared parking reservation and allocation with the goal of maximizing profit for optimal matching; Duan Manzhen et al [10] used a two-layer planning model to effectively solve the local congestion problem generated by parking allocation, taking into account peak supply constraints and walking distance; Li Shaoyan [11] took regional parking policy differences, parking industry industrialization and supply structure as the starting point , proposed an easy-to-implement and diverse forms of parking location strategies; Zhang Wenhui [12] established a dual-objective parking allocation model that maximizes the utilization rate of shared parking spaces and minimizes the walking distance, and used a particle swarm algorithm to determine the demand allocation scheme. For the sharing of regional types of buildings, Liu Zhigang [13] focused on the sharing potential of shopping mall parking spaces, analyzed the characteristics of drivers' selection behavior, and adjusted their sharing time windows, and the results showed that increasing the parking fee price could increase the number of shareable parking spaces as well as the sharing time; Wang Hao residential area sharing conducted vacant parking space prediction, and established a shared parking by binary logistic regression analysis Wang Hao has predicted the vacant parking spaces and established a shared parking behavior and pricing model through binary logistic regression analysis, which fills the gap in the theory of external sharing in residential areas [14]; Zheng Jingheng, Chen Qin and Fu Xingsheng have also studied the time-varying demand characteristics or shared parking behavior in residential areas subsequently [15-17]. Most of the studies on parking sharing in the above literature consider the allocation of shared parking spaces for specific attribute parking lots from the traveler's perspective, and there are fewer relevant studies that consider parking space sharing management schemes from an overall perspective to improve the balanced utilization of regional parking spaces.

Therefore, from the perspective of managers, this paper proposes an overall planning scheme for vehicle parking in the region, takes the minimum equilibrium index of utilization rate of adjacent parking lots in the region and the minimum walking distance as the objectives, establishes a balanced utilization model of regional shared parking spaces, and uses genetic algorithm to solve the objective function so that the difference in utilization rate of adjacent parking lots in the region is kept to a minimum, and realizes the purpose of fully utilizing all parking resources in the region.

2. Parking Space Sharing Feasibility

Two of the basic elements are whether there is time complementarity between parking demand and parking supply, and whether the walking distance after parking is acceptable to drivers. Assuming that the parking facilities in the region have the conditions for external sharing, this paper takes Tangshan City as an example to investigate the parking situation and analyze the findings.

Through the hospital daytime each time for incoming vehicles analysis as shown in Figure 1, from each time to see from 6:00-7:00 hospital parking demand began to increase significantly, after 7:00-8:00 incoming vehicles still a lot, but due to parking lot parking saturation, incoming volume began to show a downward trend, 8:00-9:00 incoming volume tends to be stable, 12:00-13: At 8:00-9:00, the number of entrances tends to stabilize, and at 12:00-13:00, the number of entrances starts to increase slowly again, and reaches a peak at 15:00-16:00. By analyzing Figure 2, we can understand that the volume of entry starts to increase gradually from 6:00-7:00, and reaches the peak of entry from 8:00-9:00 until 11:00-12:00, when the volume of entry starts to increase slowly again. Figure 3 shows the time series of the mall admissions, which gradually increase from 7:00-8:00 until the peak of admissions at 9:00-10:00, and start to show slight fluctuations in the subsequent periods.

Comprehensive analysis of Figure 1, Figure 2 and Figure 3, it can be seen that 6:00-8:00 hospitals and residential areas into the field began to gradually rise, the mall into the field less; 15:00-16:00 after the hospital and mall into the field reached saturation began to reduce, residential areas into the field began to rise, so the hospital, residential areas, shopping malls in time there are different degrees of complementarity.

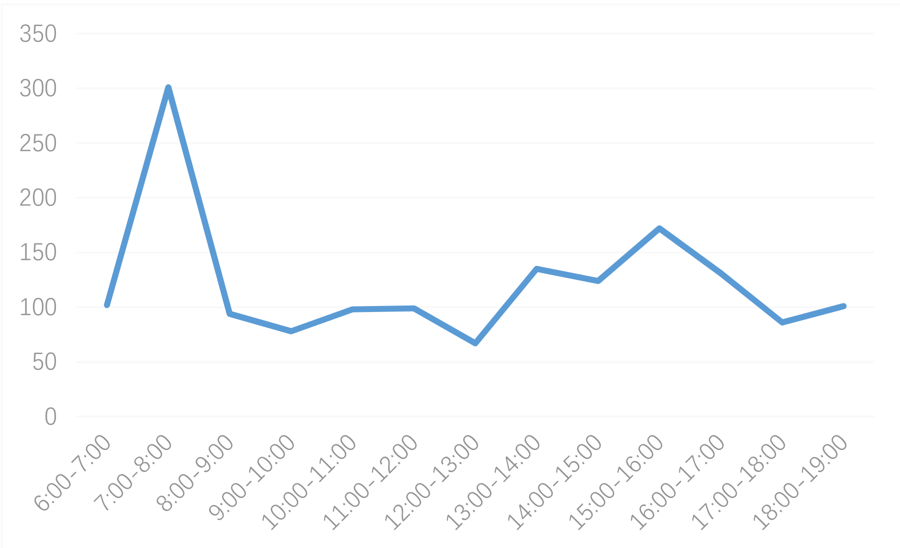

Figure 1. Hospital demand timing chart

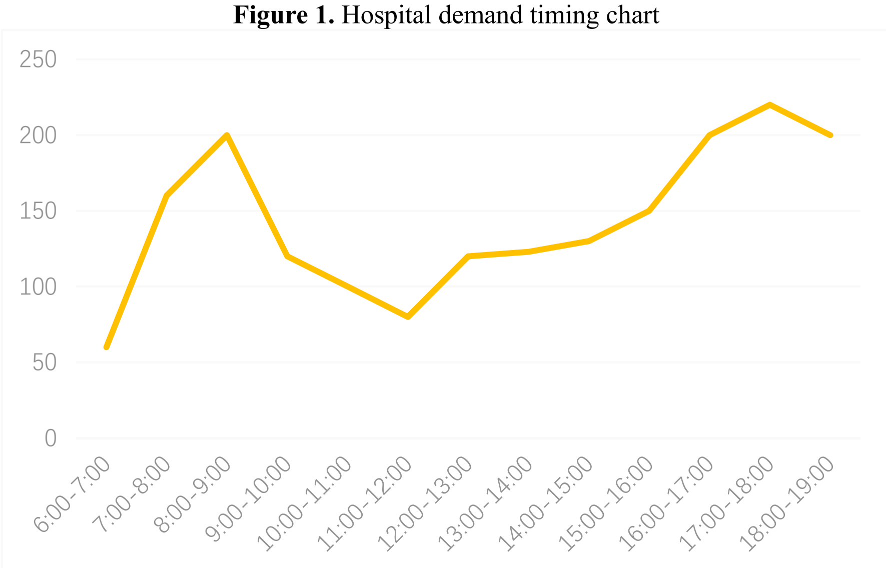

Figure 2. Demand timing map of the residential area

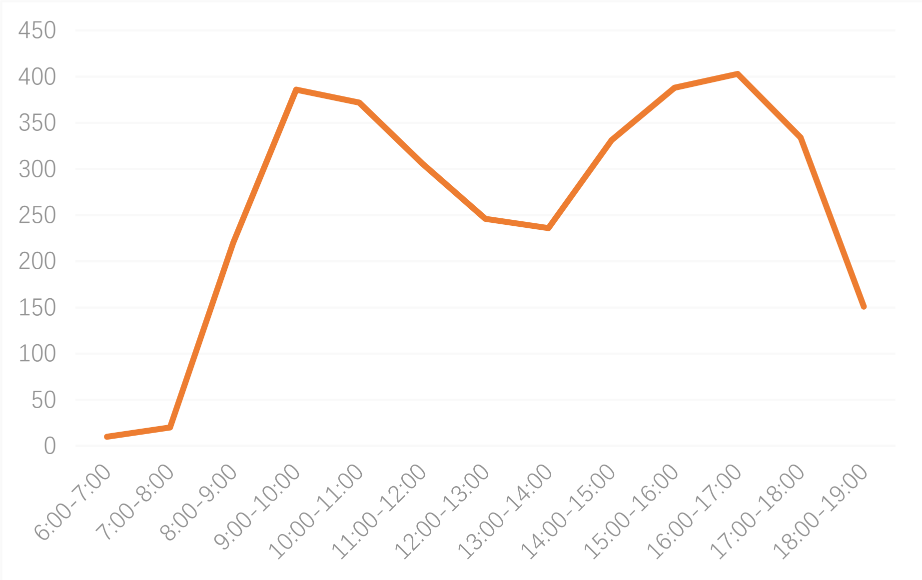

Figure 3. Time sequence diagram of shopping malls

Different travel purposes and parking duration have a direct impact on the acceptance of parking walking distance, and for medium-sized cities, the maximum acceptable walking distance for 95% of users is 350m [18]. Moreover, most of the residential, commercial, office and medical sites in China exist adjacent to each other in urban planning and design, and the concentration of urban living sites is a favorable condition for shared parking implementation [19].

3. Model Construction

3.1. Analysis of the problem of balanced utilization of regional berths

Within the shared area of the city, indicate the parking lot within the area and number the parking lot with numbers $P_1, P_2, \cdots, P_i, \cdots, P_N$, inside $i \in N, i = 1,2,\cdots,N$, These parking lots include buildings with different use properties, such as commercial, residential and office buildings.The parking space utilization rate is denoted by R, Since the occurrence of parking demand varies from time to time, it is necessary to include a time dimension to express the objective function for different time periods.Suppose there is a total of M periods, $t \in M, t = 1,2,\cdots,M$, Take the parking lot P_i as an example, the utilization rate of parking spaces in different time periods are $R_{i1}, R_{i2}, \cdots, R_{it}, \cdots, R_{iM}$.

The parking space utilization rate R is the ratio of parking space occupancy Q to the total number of parking spaces Z in the parking lot.The sum of the number of vehicles entering the parking lot in time period t and the original parking volume is denoted as X_{it}, The volume of vehicles leaving the parking lot in this period is Y_{it}, $X_{it} - Y_{it}$ is then equal to the berth occupancy Q for this period.

The model first makes a judgment on the destination parking lot, if the parking space utilization rate is less than 0.9, it means that the parking lot has more empty parking spaces, if the parking space utilization rate is greater than 0.9, it means that the parking lot is about to reach saturation, at this time, the nearby parking lots are sorted according to the distance from near to far, and the parking conditions are judged in turn until the parking space utilization rate is less than 0.9, the specific flow chart As shown in Figure 4.

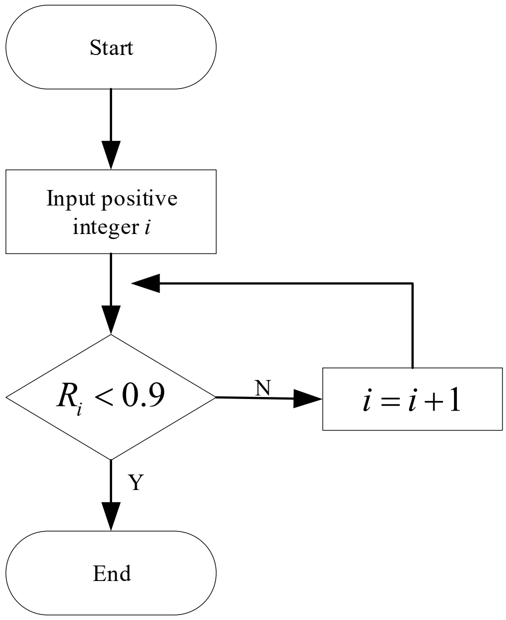

Figure 4. Flow chart of parking judgment

3.2. Model Parameters

The symbols in the model and their definitions are shown in Table 1:

Table 1. Symbols and definitions in the model

symbol	definition
S	Shared area
$P_1, P_2, \cdots, P_i, \cdots, P_N$	P is for Parking
$i \in N, i = 1,2,\cdots,N$	N is the total number of parking lots in the area
R	Berth utilization
$t \in M, t = 1,2,\cdots,M$	M is the total number of time slots
Q	Parking space usage
Z	Total number of parking spaces
X_{it}	The sum of parking lot entry and original parking volume
Y_{it}	Number of vehicles leaving the parking lot
K	Parking space balance utilization index
L	Walking distance after the vehicle is parked
$L_{\max}$	Maximum walking distance after the vehicle is parked
$C_j = C_1, C_2, \cdots, C_J$	Vehicle number, where j is a positive integer
b	Decision variable, as 0 or 1

3.3. Model hypothesis

(1) It is assumed that there are ≥1 parking lots near each destination. Each parking lot in the region uploads parking information to the platform database, and through the platform visualization can view the parking space utilization rate of each parking lot in the region in real time, making the regional parking information public and realizing the purpose of fully utilizing parking resources.

(2) The local government in the region is willing to encourage the development of regional shared parking, and can attract residents and investors to join the regional shared parking program through economic policies and financial subsidies.

(3) All parking lots in the region are under the unified management of the regional shared parking platform, with strict traffic control, mature guidance technology, guidance services and favorable sharing rates.

(4) There is no difference in parking facilities and parking environment, and there will be no influence on drivers' parking choices due to good or bad parking environment.

(5) It is assumed that drivers in the shared area understand and comply with the relevant rules in the area. All car owners can check the parking utilization rate of the destination parking lot and its nearby parking lots through the platform client before departure, and choose the destination parking lot according to the real-time situation.

3.4. Target function construction

(1)The objective function1 utilizes the highest degree of equilibrium and shows the lowest degree of variance

Under the premise of limited parking resources, in order to help relieve the pressure of urban traffic, make the overall parking rhythm more stable and not to have the situation of excessive pressure in local parking lots, choose the minimum parking space balance utilization index K as the objective function, and achieve the purpose of balanced utilization of regional parking lots by controlling the difference of parking space utilization of adjacent parking lots, and construct the utilization optimization model as follows:

$$K_{\min} = \sum_{i=1}^{N}\sum_{t=1}^{M}\left|R_{it} - R_{(i-1)t}\right| \quad (1)$$

Inside:

$$Q_{it} = \sum_{i=1}^{N}\sum_{t=1}^{M}(X_{it} - Y_{it}) \quad (2)$$

$$R_{it} = \frac{Q_{it}}{Z_i} \quad (3)$$

The constraint is:

$$\sum_{i=1}^{N}\sum_{t=1}^{M} R_{it} < 0.9 \quad (4)$$

$$Q_{it} \le Z_i \text{ ,Where } Z_i \text{ is a positive integer} \quad (5)$$

Constraint (4) When the parking space utilization rate is greater than or equal to 0.9, it means that the parking lot usage is about to reach saturation at this time, and the driver is recommended to choose a parking lot less than 0.9 for parking according to the utilization rate. In other words, if the parking lot is about to be saturated when there is a demand for parking in a certain parking lot, it is recommended to find a parking lot suitable for parking in the adjacent building. The number of parking spaces is limited, and to ensure the internal order of the parking lot, a constraint (5) is set to indicate that the number of parking spaces used in the parking lot will never exceed the total number of parking spaces in the parking lot.

Drivers can log on to the regional visualization shared parking management platform to view the parking rate of the destination parking lot and surrounding parking lots, breaking information silos and avoiding ineffective cruising and waiting due to difficult parking problems upon vehicle arrival, which largely relieves the pressure of excessive traffic flow in the parking lot during peak hours and keeps the roads open to the maximum extent.

(2) Objective function 2 The shortest walking distance after the vehicle is parked and the closest distance to the destination car park

Usually when drivers choose a parking space, an important factor that influences the choice of parking demanders is the walking distance after parking. Assuming the same parking rate in the region, the walking distance from the parking lot to the destination is L 。 b_{i+k} is the decision variable，If the utilization rate of the berth is less than 0.9 at this time, it means that it is suitable for parking to mark $b_{i+k} = 0$; Otherwise, it is recorded as $b_{i+k} = 1$ 。 C_j for driver，j is a positive integer representing the driver number.The walking distance objective function model is as follows:

$$L = \min L_{(i,i+k)}^{C_j} \cdot b_{i+k} \tag{6}$$

The constraint is:

$$L_{(i,i+k)} \le L_{\max} \tag{7}$$

The walking distance after parking is the walking distance from the parking lot to the destination, so the design of the walking distance needs to be appropriate, according to the survey, for medium-sized cities, 95% of drivers can accept a maximum walking distance of 350m.Here we assume that the maximum walking distance after parking is $L_{\max}$ .Constraint (7) indicates that the walking distance from the parking lot to the destination will not exceed the maximum walking distance.

3.5. Model solving

Genetic algorithms are also known as evolutionary algorithms. Genetic algorithm is a heuristic search algorithm inspired by Darwin's theory of evolution and borrowed from the biological evolution process. In a genetic algorithm, the set of solutions is called a population, each solution in the population is called an individual, the solution effectiveness of the solution is called the performance type, and the evaluation index of the solution effectiveness is called the fitness value. The flow of optimal solution search using genetic algorithm is shown in Figure 5, and its specific steps are as follows.

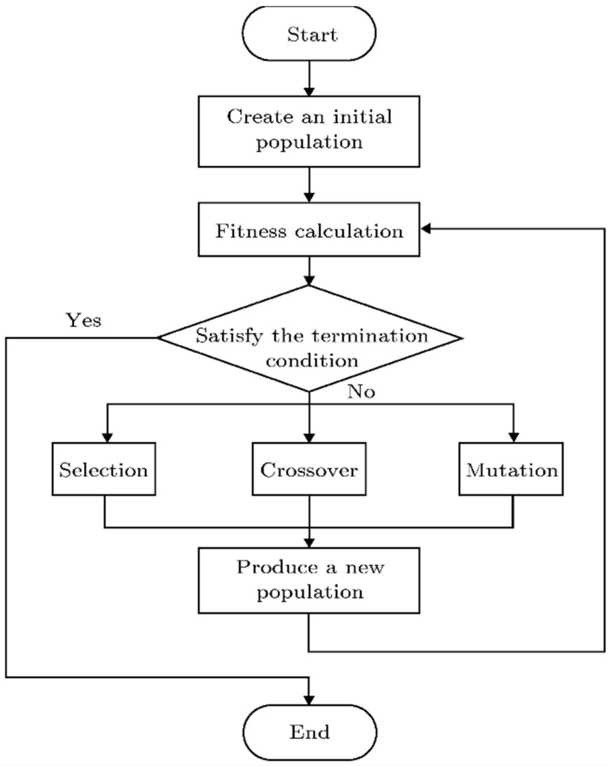

Figure 5. Flow diagram of the algorithm

Step 1 Encoding. Encoding refers to the representation of the solution data into the genotype string data structure of the genetic space, which is the first step in abstracting the actual problem into a mathematical problem and is also the basis for solving the problem using genetic algorithms. The length of the encoding directly affects the accuracy of the computational results and the computational efficiency of the algorithm. In the processing of practical problems, binary encoding is often used, and the length of the encoding is generally determined according to the requirements of the accuracy of the results.

Step 2 Initial population generation. Initial population generation is the random generation of n initial data strings, each of which can represent a solution and is equivalent to providing an initial input to the algorithm, which is a necessary starting condition for general intelligent search algorithms.

Step 3 Adaptation evaluation. The fitness evaluation refers to the evaluation of the fitness value of the solution by constructing a fitness function; the higher the fitness value, the better the solution; conversely, the worse the solution. This is the key to the solution using genetic algorithm, and the selection of the fitness function affects the subsequent computation process and the convergence of the algorithm.

Step 4 Selection. The purpose of selection is to select the best individuals from the current population to reproduce the next generation as the parent, and selection reflects the Darwinian principle of survival of the fittest. Usually, selection is carried out by using the betting round selection or league selection method according to the magnitude of fitness value, and selection also has an important influence on the convergence of the algorithm.

Step 5 Crossover. Crossover is the primary genetic operation that mimics the mating process in nature by combining the characteristics of parent individuals through crossover. Crossover ensures the stability of the population and evolves towards the optimal solution.

Step 6 Mutation. Mutation is the random change of the value of a string in the string data structure with a certain probability for selected individuals, which, as in biology, occurs with low probability. Variation ensures the diversity of the population and avoids the local convergence that can occur from crossover.

After completing step 6, steps 3 to 6 are repeated for optimal solution search, controlling the process of the algorithm by genetic algebra or error.

4. Case Study

4.1. Study area and data collation

(1) Study area selection

In this paper, the main urban area of Tangshan City, the intersection of North Construction Road and East Changhong Road, including the Second Municipal Hospital, Media Building, Yanshan Cinema, China Construction Bank and Industrial and Commercial Bank of China, four residential areas of Yingchun Building, Heping Building, Unity Building and Yingchun Building, the geographical location is shown in Figure 6

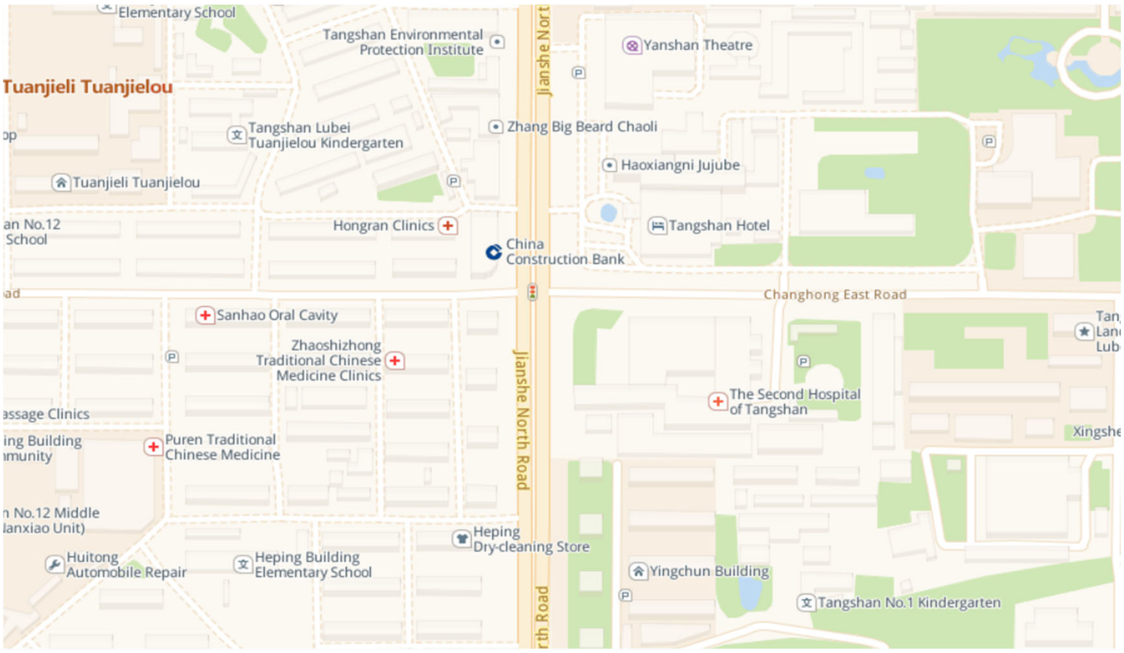

Figure 6. Schematic representation of the location of the study area

(1) Simulation base data

(2) Table 3 shows the total number of parking spaces for each building, including above-ground and underground parking lots. Walking distance is the straight-line distance between each parking lot, as shown in Table 4:

Table 3. Number of parking berths

Buildings	Second hospital	Spring Festival building	Peace building	Unity building	China Construction Bank	Industrial & Commercial Bank of China	Media building	Yanshan Film Theater	Tangshan hotel	Spring in the prosperous building
Total number of parking berths	628	320	628	298	120	86	220	130	200	80

Table 4. Distance between the various parking lots

Buildings	Second hospital	Spring Festival building	Peace building	Unity building	China Construction Bank	Industrial & Commercial Bank of China	Media building	Yanshan Film Theater	Tangshan hotel	Spring in the prosperous building
Tangshan Second Hospital	20	130	310	340	200	240	160	250	320	260

In this paper, we use the data obtained from the survey to enter each parking lot as the parking request data, taking the Tangshan Second Hospital as an example, the peak period of hospital consultation is around 7:00 on weekdays, and the closing time is usually around 12:00 at noon, so we choose the survey time from 7:00 to 12:00, and record the data every 10 min on average, the parking demand data of Tangshan Second Hospital is shown in Table 5. The parking demand data of Tangshan Second Hospital is shown in Table 5, and the utilization rate of parking spaces and the number of parking spaces in the region are shown in Table 6.

Table 5. Parking Requirements

Time Period	Second hospital
7:00-7:10	52
7:10-7:20	67
7:20-7:30	38
7:30-7:40	47
...	...
11:30-11:40	17
11-40-11:50	15
11:50-12:00	12

Table 6. Utilization rate of parking lots in the area

Time Period	Second hospital	Spring Festival building	Peace building	Unity building	China Construction Bank	Industrial & Commercial Bank of China	Media building	Yanshan Film Theater	Tangshan hotel	Spring in the prosperous building
7:00-7:10	0.67	0.89	0.86	0.9	0.36	0.34	0.37	0.33	0.75	0.76
7:10-7:20	0.68	0.88	0.85	0.89	0.37	0.35	0.38	0.34	0.69	0.7
7:20-7:30	0.7	0.71	0.68	0.72	0.37	0.35	0.38	0.34	0.64	0.65
7:30-7:40	0.86	0.87	0.84	0.88	0.41	0.39	0.42	0.38	0.66	0.67
...	...	...	...	...	...	...	...	...	...	...
11:30-11:40	0.76	0.73	0.7	0.74	0.71	0.69	0.74	0.95	0.76	0.77
11-40-11:50	0.77	0.74	0.71	0.75	0.72	0.7	0.75	0.97	0.8	0.81
11:50-12:00	0.78	0.75	0.72	0.76	0.73	0.71	0.76	0.94	0.85	0.86

4.2. Parameter setting and analysis of the experimental results

(1) Simulation parameters setting

In this paper, by assigning weights to the multi-objective function and converting it into a single objective to be solved by genetic algorithm, the parameters are set as follows: the number of populations is 200, the number of evolutionary generations is 100, and the crossover probability and variation probability are set to 0.7 and 0.08, respectively.

(2) Analysis of simulation experiment results

The above model of parking sharing scheme is simulated by using genetic algorithm in python environment to realize the decision-making process of parking equilibrium allocation by the shared parking platform. Table 7 shows the shared parking equilibrium allocation scheme, and Table 8 shows the parking utilization rate of each parking lot after the equilibrium of the simulation output.

Table 7. Allocation Scheme for Parking Demand

Time Period	Second hospital	Spring Festival building	Peace building	Unity building	China Construction Bank	Industrial & Commercial Bank of China	Media building	Yanshan Film Theater	Tangshan hotel	Spring in the prosperous building
7:00-7:10	14	9	7	6	0	2	2	6	4	2
7:10-7:20	10	9	7	11	7	7	8	4	2	2
7:20-7:30	11	6	6	4	5	4	0	0	1	1
7:30-7:40	11	7	6	3	4	3	7	1	3	2
...	...	...	...	...	...	...	...	...	...	...
11:30-11:40	6	1	2	3	2	0	0	2	1	0
11-40-11:50	7	3	2	2	0	0	0	1	0	0
11:50-12:00	6	1	2	0	1	0	0	2	0	0

Table 8. Equilibrium utilization of parking berths in the region

Time Period	Second hospital	Spring Festival building	Peace building	Unity building	China Construction Bank	Industrial & Commercial Bank of China	Media building	Yanshan Film Theater	Tangshan hotel	Spring in the prosperous building
7:00-7:10	0.88	0.89	0.86	0.9	0.36	0.44	0.47	0.53	0.75	0.76
7:10-7:20	0.82	0.88	0.85	0.89	0.57	0.55	0.58	0.54	0.69	0.7
7:20-7:30	0.84	0.71	0.68	0.72	0.37	0.35	0.38	0.34	0.64	0.65
7:30-7:40	0.89	0.87	0.84	0.88	0.41	0.39	0.42	0.38	0.66	0.67
...	...	...	...	...	...	...	...	...	...	...
11:30-11:40	0.79	0.73	0.7	0.74	0.71	0.69	0.74	0.95	0.76	0.77
11-40-11:50	0.86	0.74	0.71	0.75	0.72	0.7	0.75	0.97	0.8	0.81
11:50-12:00	0.9	0.75	0.72	0.76	0.73	0.71	0.76	0.94	0.85	0.86

The parking utilization of each location after the output of the shared parking allocation scheme. As can be seen in Figure 7, compared to the parking utilization rate before the shared parking allocation, the parking utilization curve becomes more balanced after the allocation, which fully verifies that the implementation of shared parking balanced allocation can make effective use of the parking resources in the region.

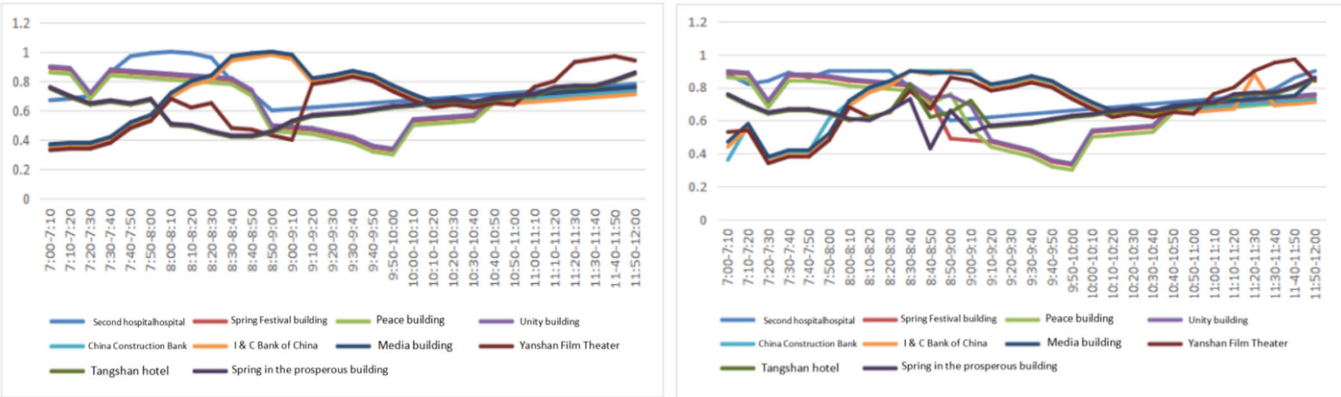

Figure 7. Comparison of berth utilization before and after equilibrium

Comprehensive analysis, through the parking demand of Tangshan Second Hospital in the region of the balance distribution of the average, so that the parking utilization rate of adjacent parking lots in the region of the smallest difference, and consider the needs of drivers walking distance after parking, using the full utilization of the surrounding vacant parking resources to alleviate the parking pressure of Tangshan Second Hospital, so that the overall parking utilization rate of parking lots in the region more balanced. Therefore, the balanced utilization scheme of parking in the region alleviates the problem of uneven and insufficient utilization of parking resources in the region.

5. Conclusion

Starting from the prerequisites of shared parking, this paper analyzes and studies the characteristics of each type of parking utilization to verify the feasibility of shared parking in the region. Based on the concept of parking space sharing, a parking space equilibrium utilization model with the highest degree of parking space equilibrium utilization and the minimum walking distance after parking is proposed as the objective function, and the multiple objectives are dynamically assigned into a single objective function and the model is solved by using genetic algorithm. Finally, the simulation verification of the parking equilibrium utilization model was completed by taking the area around the Second Hospital of Tangshan City as an example. The results show that the balanced utilization of parking spaces alleviates the problem of uneven and insufficient utilization of parking resources in the area, reduces local parking congestion, and alleviates the parking difficulty to a certain extent.

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