Research on the location of shared bicycle parking points based on improved NSGA-II algorithm

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Abstract: Reasonable location selection of shared bicycle parking points is an effective way to solve the current problem of shared bicycles. Considering the constraints such as the amount of shared bicycles, the number of parking points, and the capacity of parking points, a dual-objective bicycle-sharing parking point location planning model considering the cost minimization of both bike-sharing enterprises and travelers is established, and the simulated binary crossover operator and polynomial mutation operator are introduced to improve the NSGA-II algorithm to obtain the Pareto non-inferior solution set that satisfies both bike-sharing enterprises and travelers. The effectiveness of the model and the superiority of the improved algorithm are verified by the case. The results show that the model and algorithm can provide a reference for bicycle sharing enterprises in the location of parking points.

1. Introduction

As a green, environmentally healthy way of traveling, shared bicycle travel is deeply loved by the majority of travelers. At present, there are about 400 million registered users in the global bike-sharing industry. According to statistics, in 2022, the number of shared bicycle rides in Beijing will reach 937 million, with an average daily riding volume of 2.8065 million, a year-on-year increase of 7.53%. The speed of sharing bicycles. The rapid development has effectively solved the problem of the "last mile" of public travel, but due to its pick-up and stop-and-go and huge demand, it has seriously affected the traffic order and the appearance of the city. To this end, various localities have successively issued and issued management measures for shared bicycle operation services, proposing to set up shared bicycle parking areas and standardize the management of shared bicycle parking points. It is not difficult to see that the reasonable location and vehicle configuration of shared bicycle parking points are important means to solve the existing problems of shared bicycles.

Since the shared bicycle entered the market, a series of important results have been achieved through the painstaking research of scholars. At this stage, the research on the location of shared bicycle parking spots is as follows. Liu J W [1] established a multi-objective optimization model for parking point location and vehicle configuration, and the model introduced the idea of joint coverage, which was solved under deterministic and uncertain requirements respectively. Song Y [2] established a multi-level alternate coverage site selection decision model, and designed a segmented chromosome coding method to improve the NSGA-II model for solving. Yan et al. [3] studied how to select a site for a public bicycle parking spot and complete the initial vehicle configuration under different demand conditions. Guo et al. [4] considered the path selection, parking point selection and parking area service capacity constraints of shared bicycle users and established a mixed integer linear programming model to optimize the location and capacity of parking areas. Jia Y J [5] studied the multi-objective electronic fence siting problem with uncertain user needs with the optimization goal of minimizing the total cost of electronic fence site selection and maximizing the coverage of user needs. E. Ali-Askari et al. [6] embedded a hybrid greedy evolutionary algorithm based on genetic algorithm and particle swarm optimization in the SAA method to solve the location random allocation problem of the capacity-limited bicycle sharing system.

To this end, a dual-objective planning model of bicycle parking points for minimizing the construction and operating costs of bike-sharing enterprises and minimizing the travel costs of travelers was established, and the NSGA-II algorithm was designed and improved to solve it. The purpose of this study is to obtain the optimal solution to the location problem of dual-target facilities and provide site selection ideas for bicycle sharing enterprises.

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2. MODEL BUILDING

2.1. Symbol Definitions

2.1.1. Model assumptions

In order to simplify the construction and solution of the model, it is necessary to make reasonable assumptions about the model:

1. The cost of illegal parking vehicles is not included in the total cost of the system;
2. Travelers always choose the closest parking spot to borrow or return their car;
3. Travelers know the location of the parking spots, the number of bicycles and the number of parking spaces remaining, and can check them in real time through their mobile phones;
4. Demand, fixed construction costs, facility capacity, etc. are deterministic parameters that are applicable to the future.

2.1.2. Symbol definition

\( i \) indicates the demand point number, \( i \in N \);

\( j \) indicates the parking point number, \( j \in M \);

\( d_{ij} \) represents the distance from demand point \( i \) to parking point \( j \);

\( o_i \) indicates the number of trips of shared bicycles at point \( i \);

\( d_i \) indicates the travel attraction of shared bicycles at point \( i \);

\( T_b \) represents the average turnover rate of shared bikes;

\( T_c \) represents the average turnover rate of shared bicycle parking spots;

\( Z_j \) indicates that the largest number of shared bicycles are placed at alternative parking spot \( j \);

\( \theta \) represents the conversion coefficient of travel distance into cost;

\( P_1 \) indicates the unit price of the shared bicycle;

\( P_2 \) represents the fixed cost of setting up a parking point at \( j \);

\( P_3 \) represents the cost of repairs and depreciation of shared bikes;

\( P_6 \) denotes the overhead;

\( y_j \) represents the decision variable of whether point \( j \) is selected as the parking point, if point \( j \) is the parking point, \( y_j = 1 \), otherwise \( y_j = 0 \);

\( m_{ij} \) indicates whether the demand for the car at point \( i \) is allocated to point \( j \), if the demand is allocated to point \( j \), \( m_{ij} = 1 \), otherwise \( m_{ij} = 0 \);

\( n_{ij} \) indicates whether the parking demand at point \( i \) is assigned to point \( j \), if the demand is allocated to point \( j \), \( n_{ij} = 1 \), otherwise \( n_{ij} = 0 \);

\( A_j \) indicates whether point \( j \) is selected as a parking spot, and if the point is a parking spot, the amount of shared bicycles is set as a decision variable.

2.2. Mathematical models

The multi-objective site planning model of shared bicycle parking spots is as follows:

\[
\min W_1 = \sum_{j=1}^{M} \left( p_1 A_j + p_2 y_j + p_3 A_j + p_4 y_j c_j \right) \quad (1)
\]

\[
\min W_2 = \theta \left[ \sum_{i=1}^{N} \sum_{j=1}^{M} d_{ij} \left( m_{ij} A_j + n_{ij} c_j \right) \right] \quad (2)
\]

\[
\sum_{j=1}^{M} m_{ij} = 1 \quad \forall i \in N \quad (3)
\]

\[
\sum_{j=1}^{M} n_{ij} = 1 \quad \forall i \in N \quad (4)
\]

\[
y_j \geq m_{ij}, \quad \forall i \in N, j \in M \quad (5)
\]

\[
y_j \geq n_{ij}, \quad \forall i \in N, j \in M \quad (6)
\]

\[
\sum_{j=1}^{M} A_j T_b \geq o_i, \quad \forall i \in N, j \in M \quad (7)
\]

\[
\sum_{j=1}^{M} c_j n_{ij} T_c \geq d_i, \quad \forall i \in N, j \in M \quad (8)
\]

\[
c_j \geq A_j, \quad \forall j \in M \quad (9)
\]

\[
Z_j y_j \geq c_j, \quad \forall j \in M \quad (10)
\]

\[
y_j \in \{0,1\}, \quad \forall j \in M \quad (11)
\]

\[
m_{ij} \in \{0,1\}, \quad \forall i \in N, j \in M \quad (12)
\]

\[
n_{ij} \in \{0,1\}, \quad \forall i \in N, j \in M \quad (13)
\]

\[
A_j \geq 0, \quad \forall j \in M \quad (14)
\]

\[
c_j \geq 0, \quad \forall j \in M \quad (15)
\]

Objective formula (1) represents the minimization of the construction and operating costs of bike-sharing enterprises; Objective formula (2) represents travelers minimize travel costs. Constraint (3) and (4) indicate that each time a parking point is selected to provide users with borrowing and returning services, and different parking points can provide services for them regardless of the
same parking point; Constraints (5) and (6) indicate that after the shared bicycle parking spot is selected, the parking spot can provide borrowing and returning services for travelers; Constraint (7) indicates that the initial number of bicycles placed at the parking point should be greater than or equal to the demand for shared bicycles allocated to the parking point; Constraint (8) indicates that the capacity of the shared bicycle at the parking point should be greater than or equal to the demand for the return of the shared bicycle allocated to the parking point; Constraint (9) indicates that when the shared bicycle is initially launched, the amount of bicycle should not exceed the capacity of the parking point; constraint (10) indicates that the capacity of the parking point does not exceed the maximum capacity of the parking point; (11), (12), and (13) represent 0-1 variables; (14)(15) means \( A_j, c_j \) is not negative.

3. NSGA-II algorithm improved design

3.1. Simulate binary crossovers and polynomial variations

The SBX operator is a kind of crossover operator that simulates single-point binary, which is mostly used to encode real numbers and process multi-objective optimization algorithms. Set the parent individual as \( x_1, \ldots, x_i \) and \( x_2, \ldots, x_i \). Using the SBX operator to generate two offspring individuals \( c_1, \ldots, c_i \) can be calculated by the following equation (16):

\[
\begin{align*}
\beta &= \left\{ \begin{array}{ll}
(\text{rand} \times 2)^{\beta} & \text{rand} \leq 0.5 \\
(1/(2-\text{rand} \times 2))^{\beta} & \text{otherwise}
\end{array} \right.
\end{align*}
\]

\[\beta = \left\{ \begin{array}{ll}
(\text{rand} \times 2)^{\beta} & \text{rand} \leq 0.5 \\
(1/(2-\text{rand} \times 2))^{\beta} & \text{otherwise}
\end{array} \right. \]  

4. Case Study

4.1. Case building

The demand for shared bicycles can be divided into five aspects: education, office, commercial, residential and transportation according to the purpose of travel, and after investigation, the area around a university with five travel purposes was selected as the research object, and the shared bicycle system in the area was constructed, including 12 demand points and 18 alternative parking points, as shown in Figure 1. The travel data selects a day in May when the weather is fine and divides the demand for shared bicycles into 24 parts.

4.2. Algorithm comparison

Programming using MATLAB, according to the improved NSGA-II algorithm design process, the maximum number of iterations is set to 1000, the population size is set to 50, the SBX operator and the polynomial variation operator are selected, and after the iteration is completed, twenty

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**Table 1 Parameter values**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>( P_1 )</th>
<th>( P_2 )</th>
<th>( P_3 )</th>
<th>( P_4 )</th>
<th>( \Theta )</th>
<th>( T_b )</th>
<th>( T_s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numeric value</td>
<td>350</td>
<td>0.9</td>
<td>1000</td>
<td>30</td>
<td>1</td>
<td>2.3</td>
<td>1.9</td>
</tr>
</tbody>
</table>
optimal site selection solutions are output, as shown in Figure 2.

Fig. 2 Comparison between the improved NSGA-II algorithm and the NSGA-II Pareto algorithm

(1) In the convergence of the algorithm. The comparison results of the Pareto optimal frontier obtained by the two algorithms are shown in Figure 2, intuitively, the Pareto frontier obtained by the improved NSGA-II algorithm under the same conditions is at the bottom left of the NSGA-II algorithm, and the quality of the solution is significantly better than that of the NSGA-II algorithm. As shown in Table 2, the improved NSGA-II algorithm is significantly lower than the NSGA-II algorithm in terms of both enterprise construction and operating costs and traveler generalized costs, indicating that its search space is larger. In summary, the improved NSGA-II algorithm obtains a better Pareto frontier, and its convergence is better than that of the NSGA-II algorithm.

Table. 2 Performance comparison between the improved NSGA-II algorithm and the NSGA-II algorithm

<table>
<thead>
<tr>
<th>Optimal object</th>
<th>The total cost of enterprise construction and operation/yuan</th>
<th>Traveler generalized cost/yuan</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average value</td>
<td>Optimum</td>
</tr>
<tr>
<td>Improved NSGA-II algorithm</td>
<td>447888.8</td>
<td>442892.3</td>
</tr>
<tr>
<td>NSGA-II algorithm</td>
<td>449281.3</td>
<td>443892.3</td>
</tr>
</tbody>
</table>

(2) As can be seen from the running time of the algorithm, the average running time of the NSGA-II algorithm is 25.87s, while the average running time of the improved NSGA-II algorithm is 25.59s. It can be seen that the improved NSGA-II algorithm improves the run time.

In summary, the improved NSGA-II algorithm has improved performance compared with the traditional NSGA-II algorithm.

5. Conclusions and prospects

The site selection and planning of shared bicycle parking spots were studied. On the basis of considering the constraints of the number of shared bicycles, the number of shared bicycle parking points, and the capacity of each parking point, a multi-objective planning model was established to minimize both the construction and operating costs of bicycle sharing enterprises and the travel costs of travelers. In the process of model solving, the improved NSGA-II algorithm is designed to simulate binary crossover and polynomial variation to obtain the optimal solution set of Pareto, from which the bike-sharing enterprises can choose the most suitable scheme according to the actual situation of the bike-sharing. Finally, the effectiveness and feasibility of the model are verified by case analysis.

Considering the determined demand situation released by a local government and using the shared bicycle data of one of the bicycle companies, the parking point location and vehicle configuration were completed for the company. In the future, the issue of competitive site selection of multiple shared bicycles can be considered. In addition, the demand for shared bicycles is dynamically changing, and bicycle-sharing companies will schedule shared bicycles, which will also lead to changes in the demand for shared bicycles. In the future, more in-depth research can be carried out in combination with the problem of shared bicycle scheduling.

References