Optimization model of parking space allocation based on genetic algorithm in reservation system mode

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Abstract. The issue of parking space allocation is an important part of the research of intelligent transportation. In recent years, with the surge in the number of car users and the popularity of new energy vehicles, parking space resources have become tighter. At the same time, due to the wide application of the reservation system, how to choose the optimal allocation model has become a problem for scholars to discuss. In order to make full use of the ordinary parking spaces and charging parking spaces in the parking lot, this paper constructs a parking lot parking space allocation model under the reservation-based mode. On this basis, the total revenue of the operator is aimed at maximizing, and the demand and parking spaces are corresponding to each other one-to-one, and the order time window is the constraint. Through the genetic algorithm, the two-dimensional coding of the order number and the parking number is established, and the chromosome update strategy is designed and solved according to the order time window conflict matrix. Simulation experiments are carried out through MATLAB software to verify the scientific and effectiveness of models and algorithms. The results show that when the number of parking spaces is limited, the reservation system mode can effectively improve the utilization rate and total profit of parking spaces compared with the first-come, first-served parking mode, with an average improvement rate of 30% and 17% respectively.

Keywords: Intelligent transportation; Appointment system mode; Parking space allocation; Order time window; Genetic algorithm.

1. Introduction

In recent years, due to the popularity of energy-saving, environmentally friendly and high-priced new energy vehicles, parking lots equipped with charging piles have been increasing. However, with the surge in the number of car users, the serious imbalance in the number of cars and spaces has led to a large number of users needing to participate in the ineffective traffic flow of finding parking spaces, increasing the burden of urban traffic. In view of such situations, more and more parking lot operators adopt the reservation system model and allocate parking spaces reasonably. However, at present, there are few allocation models that take into account different needs, so it has important theoretical significance and practical value to study this problem.

Exploring booking patterns: Geng and Cassandras[1] proposed a novel "smart parking" system based on resource allocation and booking on and off-street, indicating that if notified, people will save a lot of time and money, and the utilization of parking spaces will increase. Chen et al. [2] discussed a smartphone-based parking reservation system to manage a limited number of parking spaces located in the city center. At present, the study is limited to the selection of arrival time, and less consideration is given to the appointment mode that can select the time window.

According to the analysis and demonstration of parking demand: Wang Hanqi[3] clarified the allocation optimization principle of shared parking spaces according to the dynamic parking needs of users, constructs a dynamic allocation model of shared parking spaces, and improves the utilization rate of shared parking spaces. Yan Wang et al. [4] considerd dynamic multi-cycle parking needs and ensure that users' parking needs are met at each time. The model is used to determine both the number and location of parking lots, the number of parking spaces in each parking lot to be built, and the number of cars that will enter or leave each parking lot in each time period at each parking demand point. Tiantian Wang[5] proposed a new mechanism to control supply and demand. On the supply side, a strategy similar to shared parking is adopted, and the system may relocate users to a nearby parking space. On the demand side, the system may ask the user to wait for a period of time to wait for the occupied space that may be freed up. Under this spatiotemporal flexible mechanism, the system service failure can be reduced to a certain threshold. Marko Mladenović et al. [6] recently released a static parking allocation model for connected vehicles that solves the problem of parking allocation for connected vehicles within a given time period, depending on the frequency of vehicle traffic. Bowen Jiang[7] discussed the optimal allocation of shared parking spaces considering unsquatched parking in a programming approach, maximizing the weighted benefits of profits from consumers minus idle and overload costs by establishing a random scheme (U-P).

From the analysis and demonstration of parking space optimization: Duan Manzhen et al. [8] proposed an individual-oriented parking guidance model for parking in the road network area. Li Changmin et al. [9] measured the probability of default of travelers by credit value, and classify and manage travelers with different credit levels, and optimize the allocation of shared parking spaces based on the classification situation. Xiao Jing et al. [10] proposed a high-dimensional multi-target parking lot selection and path induction model that comprehensively considers the user's travel before and after travel, and solves it by KS-MODE, a high-dimensional multi-objective optimization algorithm. At present, most of the research focuses on customer demand, supply and demand, and less considers the difference in parking spaces and the appointment time window.

Parking lots with mixed parking spaces can alleviate the problem of parking difficulties for users with different needs to a certain extent, but due to the lack of a good supply and demand matching model, it is easy to cause conflicts between charging and parking needs, and this conflict problem is not available in ordinary parking lots. Based on this, this paper takes the mixed parking lot as the research object and establishes a mixed integer planning model for the allocation of parking spaces in the reservation mode from the perspective of different parking needs. Then, the model is solved by genetic algorithms.

2. Optimization model of mixed parking space allocation in parking lot under reservation mode

2.1 Problem description

Consider a parking lot with mixed parking spaces that adopt a reservation mode, where customers can reserve parking spaces for the next day on the same day, choose between ordinary parking needs and charging parking needs, and select parking time windows. The parking lot allocates all the reserved bookings and informs the customer of the allocation. The parking lot has a total of M ordinary parking spaces and N charging spaces, each parking space can be parked for 24h. Suppose the parking lot receives a total of I ordinary parking space parking demand and J charging parking space parking demand, each parking demand i, i belongs to I, parking time window $[t_i^{start}, t_i^{end}]$, t_i^{dur} indicates the length of parking for each i order, every parking requirement j, j belongs to J, parking time window $[t_j^{start}, t_j^{end}]$, t_j^{dur} indicates the length of parking for each j order, the charging time is included in the parking time.

If the operator can allocate ordinary parking spaces to parking needs, the parking fee will be charged from the demand side, and the parking fee per unit duration is p_n, if the charging parking space can be allocated to the general parking demand or the charging parking demand, the parking fee will be charged from the demand side of the ordinary parking space, and the parking fee per unit duration is p_n, the parking fee is charged from the charging space demander, and the parking fee for the unit duration is p_e, the charging fee per unit duration is C. If it cannot be allocated, the order will not be accepted. This article considers how to reasonably distribute orders under the premise of knowing the order situation to maximize the profit of the operator.

Make the following basic assumptions about users, parking spaces, and prices:

Assumption 1: Users will not temporarily cancel appointments and reject operator assignments due to their own circumstances. For the convenience of calculation, each user knows exactly how long it takes to park, and the charging time of the user who needs to charge is equal to its parking time.

Assumption 2: The charging pile of the charging parking space is a variable power charging pile, and the charging power limit of the parking lot is not considered.

Hypothesis 3: Parking time in 0.5 hours.

Hypothesis 4: The choice of time window for vehicle parkability is limited to [0,24], so the time window exceeds the parking space time window constraint is not considered

Hypothesis 5: Charging demand j cannot be allocated to ordinary parking spaces m

2.2 Model parameters and variables

Table 1. Input parameter definition table

Symbol	Illustrate
M	The number of regular parking spaces
N	The number of charging parking spaces
i	Ordinary parking requirements, i= 1, 2,...., I
j	Charging power failure demand, j=1,2,....,J
$[t_i^{start}, t_i^{end}]$	Normal parking requirements i Parking start time and end time
$[t_j^{start}, t_j^{end}]$	Charging parking requirements j Parking start time and end time
t_i^{dur}	Regular parking requirements i Parking duration
t_j^{dur}	Charging parking requirements j parking duration
p_n	Unit duration parking fees for regular parking requirements
p_e	Charging parking requirements for unit duration parking fees
C	Charging cost per unit duration of the charging parking requirement
Z	Maximum value

Table 2. Decision variable definition table

X_{im}	Whether the parking request i is assigned to a normal parking space m, if allocated $X_{im}=1$, if not, $X_{im}=0$
X_{jn}	Whether the parking request j is allocated to the charging parking space n, if allocated $X_{jn}=1$, if not, $X_{jn}=0$
X_{in}	Whether the parking request i is assigned to the charging parking space n, if allocated $X_{in}=1$, if not, $X_{in}=0$

2.3 Model building

Based on the above analysis, the profit maximization objective function of the hybrid parking space model is established:

$$\text{MaxProfit}=p_1\sum_{i=1}^{I}\sum_{m=1}^{M}X_{im}t_i^{dur}+p_2\sum_{j=1}^{J}\sum_{n=1}^{N}X_{jn}t_j^{dur}+C\sum_{j=1}^{J}\sum_{m=1}^{M}X_{jn}t_j^{dur}+p_1\sum_{i=1}^{J}\sum_{n=1}^{N}X_{in}t_j^{dur}-C_1\sum_{j=1}^{J}\sum_{n=1}^{N}X_{jn}t_j^{dur}$$

Among them, the first item represents the benefits of allocating ordinary parking spaces to ordinary demand, the second and third items represent the benefits of allocating charging parking spaces to charging needs, the fourth represents the benefits of allocating ordinary parking spaces to charging parking spaces, and the fifth represents the charging cost of parking lots

The constraints on the allocation of parking spaces are as follows:

Any ordinary parking space demand i is allocated to a normal parking space or charging parking space at most,

$$\sum_{m=1}^{M} X_{im} + \sum_{n=1}^{N} X_{in} \le 1,\ i \in I \tag{1}$$

Any charging space requirement j is allocated to a maximum of one charging parking space

$$\sum_{n=1}^{N} X_{jn} \le 1,\ j \in J \tag{2}$$

Requests to be assigned to the same parking space should have no parking time conflicts

For any m parking space, if the i order time window is in front of the d order time window, then Z_{idm}=1, if not Z_{idm} =0

$$X_{im} + X_{dm} - 1 \le Q_{idm},\ i、d \in I,\ i \ne d,\ m \in M \tag{3}$$

$$t_i^{end} \le t_d^{start} + Z^* (2 - Q_{idm} - Z_{idm}) \tag{4}$$

$$t_i^{start} \ge t_d^{end} - Z^* (1 - Q_{idm} + Z_{idm}) \tag{5}$$

For any n parking spaces, if the i order time window is in front of the g order time window, then $Z_{ign} = 1$, if not =0

$$X_{in} + X_{gn} - 1 \le W_{ign},\ i \in I,\ g \in J,\ n \in N \tag{6}$$

$$t_i^{end} \le t_g^{start} + Z^* (2 - W_{ign} - Z_{ign}) \tag{7}$$

$$t_i^{start} \ge t_g^{end} - Z^* (1 - W_{ign} + Z_{ign}) \tag{8}$$

For any n parking spaces, if the j order time window is in front of the f order time window, then $Z_{jfn} = 1$, if not=0

$$X_{jn} + X_{fn} - 1 \le E_{jfn},\ j、f \in J,\ j \ne f,\ n \in N \tag{9}$$

$$t_j^{end} \le t_f^{start} + Z^* (2 - E_{jfn} - Z_{jfn}) \tag{10}$$

$$t_j^{start} \ge t_f^{end} - Z^* (1 - E_{jfn} + E_{jfn}) \tag{11}$$

3. Solve the algorithm

3.1 Chromosome encoding

The parking space allocation problem is NP-based, while the genetic algorithm has the characteristics of implicit parallelism and global information requirements, which is a powerful way to search for a series of tasks to find the optimal solution to the system. Therefore, in order to efficiently find the optimal solution in a complex set of modified parameters, genetic algorithms are introduced. The most commonly used coding method of genetic algorithm is binary coding, but the particularity of parking space allocation determines that the use of binary coding is not suitable for solving, so this paper uses the two-dimensional coding method of order number - parking number. For example, the supplier received a total of 6 ordinary parking space demand, the order number is 1-6, 4 charging parking space demand, the order number is 7-10, there are 6 available parking spaces, the parking space number is 1-6, then first set a 2 * 10 zero matrix, the first line is a scrambled 10 order numbers, and the second line is assigned a random integer between 1-6 for each order number. The value of column i in the second row of the matrix is the order-parking space number. Figure 1 represents a chromosome, and the fourth column of the second row indicates that order 6 is allocated in parking space 5.

5	4	7	6	3	1	10	9	8	2
4	3	1	5	6	2	3	4	2	1

Fig. 1 Chromosome example

3.2 Initial population

The process of population initialization is a mixed screening method that combines the random individual generation rules and heuristic rules, and the random individuals who are generated are tested to determine whether their behavior can fully meet the conditions of the constraint, and the two main problems considered are parking space designation and time window conflicts.

Step 1: Determine the set of available parking spaces and select them randomly.

Step 2: Calculate the time window constraint, if the parking space already has an order, calculate whether the time window of the next order conflicts with the time window of the current order, if there is a conflict, skip the next order, and set the parking time of the order to 0; If there is no conflict, the calculation continues later.

Step 3: Update the data

3.3 Adaptability function

Since the proposed model attempts to maximize the combined profit (Maxprofit), the adaptability function can be –Maxprofit.

3.4 Genetic manipulation

Genetic manipulation mainly includes selection, crossover and variation manipulation.

(1) Selection operation: The purpose of population selection is to select a better individual form of the initial demand - parking number code group, and as the parent of the next generation. The criterion for judging the merits of individuals is the result of the fitness function of each solution set. The higher the individual's fitness value, the greater the likelihood of being selected by the next generation. Depending on the characteristics of the fitness function, the roulette method is chosen here.

(2) Cross-operation: Due to the influence of intergenerational replication, the solution in the breeding pool increases the economic benefits of the entire system. Since the replication process does not produce a new set of coordinates, the fitness of the optimal individual in the population does not decrease. The cross-process acts on two populations randomly selected from a mating pool. By selecting a group with better individual needs-parking spaces, the last generation will contain the best genes for the parent string.

Select a pair of individuals as parent individuals 1 and parent individuals 2, as shown in Figure 2.

9	10	7	6	3	1	5	2	4	8
4	6	1	1	2	3	3	5	6	5
parent individuals 2									
5	10	9	7	4	3	6	1	2	8
3	5	6	1	1	2	3	4	5	2
parent individuals 1									

Fig. 2 Parent example

5	10	6	7	4	3	9	1	2	8
3	5	6	1	1	2	3	4	5	2
individuals 3									
6	10	7	9	3	1	5	2	4	8
4	6	1	1	2	3	3	5	6	5
individuals 4									

Fig. 3 Examples of new individuals

Generate a random number P and compare with crossover probability p_r, if $p<p_r$, then do not cross, directly copy the parent to the child, otherwise turn.

Randomly select a column and write out the corresponding element pairs. If there is no 0 element, such as column 3, the corresponding element pair is (9, 6), find the position of the order number 6 in individual 2 in individual 1 (column 7), and exchange the order number on these two positions; At the same time, find the position order number 9 in individual 1 and then the position in individual 2 (column 1), exchange the order number on these two positions, and form a new generation of individuals 3 and 4, as shown in Figure 3. Otherwise turn: If there is a 0 element, no crossover is performed

(3) Mutation manipulation: For each demand-parking coding chromosome, the probability of mutation is the same. For example, having a gene with a current value of 0 means that this demand will not be allocated a parking space. If there is a mutation, the value will be changed to 1, which means that it has some chance of being selected for the next iteration

For new individuals produced by selecting replication and crossover, the mutation operation generally does not occur because the probability of mutation is relatively small, and the mutation operation adopts a single point of variation. For each gene in an individual, a random number P is produced, if $p < p_m$, there is no variation, Otherwise, a random location is generated, and the gene in that position is exchanged with this gene, and if the randomly generated location is the same as the gene position, it is not exchanged.

In summary, the steps to achieve parking space allocation optimization using genetic algorithms are as follows:

Step 1: Initialize. Set the population size, chromosome length, number of iterations, crossover probability, and mutation probability.

Step 2: 2D coding of each demand-parking number to randomly generate the initial population.

Step 3: Calculate the fitness function for each generation using the iterative method. Sort all individuals, select the better ones, and eliminate the poorer ones to produce a new demand-parking number set.

Step 4: Cross between randomly connected individuals based on the crossover probability. Mutations are made to individual parking numbers based on the location probability of mutations.

Step 5: Confirm if the maximum number of iterations has been reached. If so, the optimal solution for parking space allocation is output. Otherwise, return to step 3 for the next round of iterative calculations.

4. Simulation calculations and analysis of results

In order to verify the effectiveness and rationality of the proposed model and algorithm, four different test sizes are set for the number of parking spaces and the number of orders. Some initial parameters are set, the unit price of ordinary parking spaces is 10 yuan / h, the unit price of charging parking spaces is 15 yuan / h, the charging cost is 10 yuan / h, and the charging cost is 5 yuan / h. The genetic algorithm takes the number of initial individuals = 100, and the maximum number of iterations = 500.

Using four sets of random studies, the difference in results between the non-appointment mode (that is, the first-come, first-served) and the reservation mode was calculated.

Table 3. Comparison results of appointment mode and non-appointment mode at different scales

Test scale		Non-reserved mode	Reservation mode		
Number of parking spaces	Order quantity	Maximum profit	Maximum profit	Profit improvement rate	Order allocation lift rate
3/2	15/10	1000(12/8)	1060(14/9)	6%	6%
6/4	30/20	1760(20/15)	2220(26/18)	26.14%	18%
8/6	60/40	2870(39/27)	3760(48/34)	31%	16%
10/8	120/80	5020(76/50)	6590(98/62)	31.27%	17%

Note: The number of parking spaces in column 1 indicates the number of ordinary parking spaces/charging spaces owned by the parking lot; The order quantity in column 2 represents the ordinary demand order quantity/charging demand order quantity

5. Summary

This paper innovatively proposes a mixed parking space allocation scheme for parking lots under the reservation system mode, and maximizes the profit of parking lots by constructing a mixed integer planning model. Although the proposed model involves a large number of parameters, these parameters can be obtained through surveys or existing research methods. Through the study analysis, we know:

(1) For the sake of maximizing the profits of platform operators, this distribution scheme will allocate ordinary parking needs to idle charging spaces while the charging needs can be preferentially met, make full use of parking space resources, and reduce the waste of parking spaces to a large extent. Compared with the non-appointment model, the profit of the reservation model increased by about 30%, and the order distribution rate increased by about 17%.

(2) With the expansion of the scale of parking lots and the increase in the number of orders, the profit gap between the reservation system model and the traditional model is gradually expanding. This paper provides a certain reference direction for the transformation of traditional parking lots to intelligent hybrid parking lots.

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