A Study on the Scheduling Problem of Car Sharing with User Participation Under Dynamic Incentives

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Abstract. Car sharing is growing rapidly worldwide, and the development of car sharing is constrained by factors such as unbalanced user travel demand and high enterprise operating costs. This paper considers the influence of multiple factors on user travel behavior, uses a multinomial logit model to encourage user participation in car-sharing dispatch, and develops a model for joint employee and user dispatch with the goal of minimizing enterprise costs. The model is validated using Qingdao city as an example, and the results show that user participation in dispatching can reduce enterprise operating costs.

Keywords: Car sharing scheduling · staff relocation · user relocation

1 Introduction

In recent years, shared electric vehicles have grown rapidly worldwide in order to accelerate economic development, promote technological innovation, reduce carbon emissions, ease traffic congestion, and improve energy use efficiency [1, 2]. In China, the fast-growing mobile Internet technology has facilitated the development of car-sharing business; before 2015, there were less than 10 car-sharing startups in China, but as of June 2018, more than 400 car-sharing companies have been registered in the country, and the number of car-sharing vehicles in operation has exceeded 100,000.

Car-sharing is in the initial rapid development stage in China, which deserves in-depth research and discussion. Most of the discussions about car sharing in the field of urban research establish car sharing scheduling models based on employee scheduling [3–6]. Employee scheduling is currently the most dominant scheduling strategy for car sharing systems, and empirical studies for different cities at home and abroad show that relevant improved models can increase the rental temporary demand and operator revenue, while reducing the system imbalance index. However, the high cost and inefficiency of employee scheduling hinder the further development of car sharing, and a few scholars study the problem of user-involved car sharing scheduling and propose that the impact of factors such as cost on the site selection behavior of shared vehicle users can be fully considered by encouraging users to return vehicles from overcrowded stations to undercrowded stations in order to achieve maximum inter-site vehicle equilibrium and

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thus reduce enterprise scheduling costs [7–9]. A stated preference experiment conducted by Curtale et al. in the Netherlands to analyze the travel preferences of one-way shared electric vehicle services showed that by granting certain discounts, users were willing to cooperate with ESC operators to actively dispatch off-site returns, and the willingness to accept rewards for extra time spent was estimated to be as high as €0.33 per minute [10]. A explored the impact of price dispatching mechanism on the self-dispatching behavior of car-sharing rental users, adjusted the existing car-sharing dispatching system, reasonably guided car-sharing rental users to self-dispatch, and improved the utilization rate of vehicles [11].

The user-based discount strategy in the current study is inflexible and does not take into account the traveler's preference for the return point of the shared car. Therefore, based on the existing research, this paper explores the influence of discount, dispatching time, riding distance after getting off, and road congestion on users' travel behavior by establishing a multiple logit model, which is used as an entry point to flexibly adjust user discounts according to actual needs, encourage users to actively participate in dispatching, combine users' active participation in dispatching with the enterprise's hired dispatching, and build a model that minimizes the enterprise's operating costs. By comparing the operating costs of employee-only scheduling with those of joint user-employee scheduling, we conclude that the introduction of reasonable user scheduling is important for car-sharing companies.

2 Dynamic Incentive Strategy for Car Sharing

The non-set-count model is a relatively simple and widely used discrete choice model, which is mainly applied to study the relationship between the probability of choosing a certain option and the characteristic variables of the decision factors. According to the utility maximization theory in the model, utility is the satisfaction generated by the user z after choosing a certain travel option, that is, the effect of this travel option on the user z. Here the utility is explained through two components together, fixed utility and random utility, which can be expressed as

$$U_{\mathrm{zn}}=V_{\mathrm{zn}}+\varepsilon_{\mathrm{zn}} \tag{1}$$

Assuming that each of the random terms is independent of each other and obeys the Gumbel distribution, Consider the set of its selected limbs as $A = \{\mathrm{n = i(Original\ plan), n = j(Current\ plan)}\}$. Then the probability that user z chooses to schedule to point j:

$$P_{\mathrm{z}}(\mathrm{j}) = \frac{\exp^{V_{\mathrm{zj}}}}{\sum_{\mathrm{n}\in A} \exp^{V_{\mathrm{zn}}}} \tag{2}$$

The effectiveness function usually takes into account the ease of analysis of the results and the convenience of the calibration of the coefficients, and the linear function form shown in Eq. (3) is widely used.

$$V_{\mathrm{zj}}=\theta_1 \cdot Y_{zj1} + \theta_2 \cdot Y_{zj2} + \theta_3 \cdot Y_{zj3} + \theta_4 \cdot Y_{zj4} \tag{3}$$

Table 1. Results of solving for unknown parameters

Characteristic variables	Effectiveness factor	*Std.Err*	*tTest*
θ_1	0.923854	0.148671	6.214100
θ_2	−0.249513	0.045240	−5.515317
θ_3	−3.084801	0.529205	−5.829123
θ_4	−1.240869	0.306735	−4.045405

Create a questionnaire, import the data into the software to solve, and solve the results as shown in Table 1.

According to Eq. (2) and Eq. (3), the amount of discount for the scheduling scheme can be obtained by finding the inverse function with known travel time, walking distance, congestion index, and selection probability of the scheduling scheme, as shown in Eq. (4).

$$Y_{zj1} = \frac{\ln\left(\frac{p}{1-p}\right) + \theta_2\left(Y_{zi2} - Y_{zj2}\right) + \theta_3\left(Y_{zi3} - Y_{zj3}\right) + \theta_4\left(Y_{zi4} - Y_{zj4}\right)}{\theta_1} + Y_{zi1} \tag{4}$$

The travel time, riding distance and congestion index are determined for the original travel scheme and the scheduling scheme, so the value of p needs to be determined to find the discount amount. Assuming that the user accepts a scheduling scheme if the probability of choosing it is greater than 1/2, $p \in (1/2, 1]$. Derivation of Eq. (4) yields that the discount increases as p increases, as shown in Eq. (5). Therefore, the lowest discount amount can be used to motivate users to choose the target scheduling scheme, as shown in Eq. (6).

$$\begin{aligned} v'_{ij} &= f'\left(p, Y_{\text{zn}1}, Y_{\text{zn}2}, Y_{\text{zn}3}, Y_{\text{zn}4}, Y_{\text{zj}2}, Y_{\text{zj}3}, Y_{\text{zj}4}\right) \\ &= \frac{1}{\theta_1 p(1-p)} \end{aligned} \tag{5}$$

$$v_{ij} = \lim_{p \to (1/2)^+} f(\cdot) \tag{6}$$

3 Car-Sharing Scheduling Optimization Model Construction

3.1 Problem Description

If the number of vehicles at the user's destination site is higher than the upper threshold or there exists a nearby site with a lower number of vehicles than the lower threshold, a vehicle dispatching situation arises, and the following dispatching scheme is designed: first, employee dispatching, i.e., the company's employees drive the customer's destination-site i vehicle to dispatching site j; second, user dispatching, using discount incentives to prompt the customer to dispatch.

3.2 Model Construction

It has been studied that the operating cost of a company decreases when users participate in car-sharing dispatching, and this paper builds on this by considering only the floating cost in the dispatching process [12]. The model seeks to minimize the total cost of dispatching, which consists of three components.

$$\min C = C_1 + C_2 + C_3 \tag{7}$$

The cost of energy consumption generated by passing through the path, which is mainly related to the loss of electricity and other losses generated by the vehicle driving, is shown in Eq. (8).

$$C_1 = \sum\nolimits_{h_t j_{t+\sigma_{hj}^t}} \sum\nolimits_{h\in H} \sum\nolimits_{i\in I} \sum\nolimits_{j\in J} (\mathrm{H_{hj}} - \mathrm{H_{hi}}) \cdot \mathrm{P_e} \cdot X_j^{h_t} + \sum\nolimits_{i_t j_{t+\sigma_{ij}^t}} \sum\nolimits_{i\in I} \sum\nolimits_{j\in J} \mathrm{H_{ij}} \cdot \mathrm{P}_e \cdot Y_j^{i_t} \tag{8}$$

If a user chooses to perform a scheduling task, the enterprise gives the user an incentive discount, incurring an incentive fee, as shown in Eq. (9).

$$C_2 = \sum\nolimits_{h_t\in X} \sum\nolimits_{h\in H} \sum\nolimits_{j\in J} \sum\nolimits_{n\in N} X_j^{h_t} \cdot v_{hj}^{t,n} \tag{9}$$

Equation (10) is the dispatcher's cost, and the company will give appropriate subsidies to the employees involved in dispatching.

$$C_3 = \sum\nolimits_{i_t\in X} \sum\nolimits_{i\in I} \sum\nolimits_{j\in J} (\sigma_{ij}^t + \omega_{ji}^t) \cdot u_{per} \cdot Y_j^{i_t} \tag{10}$$

s.t

$$v_{hj}^{t,n} = f\left(Y_{\mathrm{zj2}}, Y_{\mathrm{zj3}}, Y_{\mathrm{zj4}}\right) \tag{11}$$

$$X_j^{h_t} + Y_j^{i_t} \le 1 \tag{12}$$

$$\sum\nolimits_{i\in I} S_i^t \le N^{car}, \forall t \in [1, G] \tag{13}$$

$$1 \le r_{\mathrm{ij}}^{\mathrm{t}} \le 5 \tag{14}$$

$$S_j^t \le S_{\mathrm{pj}}^{\mathrm{t}} 或 S_{\mathrm{fi}}^{\mathrm{t}} \le S_i^t \tag{15}$$

$$S_i^t \le S_i^{park} \tag{16}$$

Equation (11) indicates the incentive discount given to the user; Eq. (12) indicates that at most one scheduling method is taken; Eq. (13) indicates that the number of vehicles at station i at any moment is less than the initial number of vehicles; Eq. (14) indicates the ratio of the actual fulfilment time of an average trip to the travel time in the free-flow state. Equation (15) indicates that the number of vehicles at site j is less than the lower threshold of the number of parking at j or the vehicles at site i is higher than the upper threshold; Eq. (16) indicates that the number of vehicles at site i at time t does not exceed the maximum capacity of the parking lot at site i.

Table 2. Car demand data

Task Number	Time	Departure Place	Destination
1	13:00	1	2
2	13:08	1	2
3	13:20	1	2
4	13:45	8	11
5	13:55	2	1
6	14:05	2	1
7	14:15	2	1
8	14:20	5	7
9	14:26	7	10
10	14:34	9	11
11	14:40	12	4
12	14:46	12	7

4 Example Application and Analysis

4.1 Case Overview

The experiment was based on the data of Qingdao area in China from "Yi Hi Car Rental", and 12 sites in Qingdao were selected based on the geographical location and regional categories. The experiment was set from 13:00–17:00 p.m. The departure points and destinations of users at different times were randomly generated as shown in Table 2.

4.2 Analysis of Results

Set the total scheduling cost of the enterprise as the objective function and set the relevant parameters $u_{per} = 0.34$ yuan, $V_a = 30$ km/h, $P_e = 0.166$ yuan/km. The solution was performed using MATLAB 2020b with 200 iterations, a population size of 50, a crossover probability of 0.5, and a variance probability of 0.1, and the solution iteration process is shown in Fig. 1. The total cost of the final output objective function is 328.67 yuan, and the optimal scheduling scheme for each station is obtained, and the results are shown in Table 3.

From Table 3, it can be concluded that the number of vehicles in the car-sharing operation system is below the threshold, i.e., the demand site, the original travel scheme path of users, the optimal dispatch scheme path by giving subsidies to users or employees, and the interval of discount amount of car-sharing incentives for users to participate in dispatching is (0.846, 5.28).

4.3 Scheduling Cost Analysis

After calculation, the floating cost of completing the dispatching plan is 94.1436 yuan for employees only, and 42.0226 yuan for encouraging users to participate in dispatching,

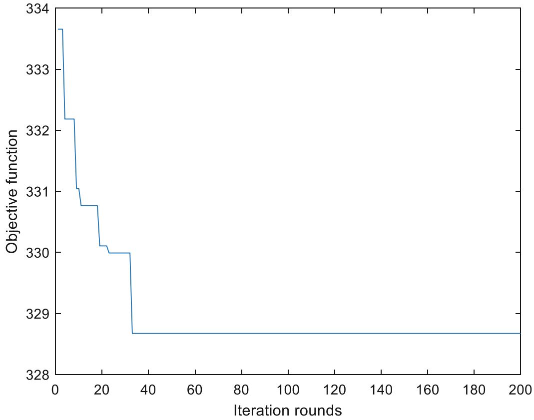

Fig. 1. Solving the iterative process

Table 3. The scheduling scheme given by the genetic algorithm

Task Number	Scheduling Solutions	Scheduling solution path	Discount amount
1’	Employee	1–2-3	3.61
2’	Employee	1–2-3	5.28
3’	User	1–3	1.94
4’	Employee	8–11–10	4.02
5’	No	–	
6’	No	–	
7’	No	–	
8’	User	5–6	0.846
9’	User	7–11	2.27
10’	No	–	
11’	No	–	
12’	No	–	

which is 55.4% lower than that of employees, while the floating cost of 28.67 yuan is 69.5% lower than that of employees only when employees and users jointly participate in dispatching. The results show that user participation in car sharing dispatching based on dynamic incentives not only enables users to receive reward amounts and enhance their willingness to actively participate in dispatching, but also further reduces the dispatching cost of enterprises and enhances their profits.

5 Conclusion

This paper establishes a multinomial logit model to study the effects of travel time, riding distance, congestion index, and incentive discounts on users' travel behavior. When the lowest discount amount can be used to prompt users to choose the target dispatching scheme, companies can develop price discount strategies according to users' actual travel conditions. The use of user-initiated dispatching can significantly improve the operating company's revenue, save costs, and reduce the cost to users than dispatching by employees only.

This paper discusses the impact of incentive strategies on car-sharing companies, but the factors that users consider in real-life situations are often dynamic and complex, so future research will focus on the factors that influence users' travel option choices.

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