Optimization of Vehicle Assignment for Car Sharing System

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Abstract. Recent advances in information technology enable realization of new on-demand transportation systems. A car sharing system is one of the new on-demand transportation systems and its concept is that people share vehicles to save maintenance cost. A car sharing system is expected as a solution for traffic jams and lack of parkings. There are two types of car sharing systems: the one-way type and the round-trip type. In this paper, we focus on the one-way type. In the one-way type, users can return vehicles to any stations at any time. Thus, it is hard to keep distribution balance of parked vehicles among stations. We propose a method for optimizing vehicle assignment according to distribution balance of parked vehicles. Finally, we report experimental results of our simulation, and evaluate the effect of our method.

Keywords: car sharing, vehicle assignment.

1 Introduction

In these years, developments of information and communication technologies become the basis of Intelligent Transport System (ITS)[1]. The advances of global positioning systems and communication techniques enables realization of new on-demand transportation system such as Demand Bus System[2]. We focus on the car sharing system [3,4,5] which is one of the new on-demand systems. The concept of the system is to share a small number of vehicles among a large number of users. There are three contributions by the system: cost sharing, earth sharing, and road sharing.

The car sharing system is classified into the one-way type and the round-trip type according to where users return a vehicle. In the round-trip type, a user has to return a vehicle at the station where the user rent it. Therefore, the round-trip type applies to a user who shall return again to the original position. On the other hand, in the one-way, a user can return a vehicle at any station. Thus, users can use vehicles like a public bus or taxi. Consequently, the one-way type is more flexible and useful than the round-trip type. However, it is hard

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to keep distribution balance of parked vehicles among stations. If distribution balance is disrupted, a lack of vehicles is occurred at any stations. As a result, it is impossible to assign vehicles to new users immediately. Therefore, the one-way type needs a mechanism for balancing parked vehicles among stations. In this paper, we propose a method for optimizing distribution balance of parked vehicles by assigning the optimum number of used vehicles to users. Thereby, it is possible to keep distribution balance of parked vehicles and keep a convenience of car sharing system. Finally, we report experimental results of our simulation, and evaluate the effect of our method.

The remainder of this paper is organized as follows: Section 2 formalizes one-way car sharing system. In Section 3, we mention assignment of the number of vehicles. In Section 4, we report simulation results and consider effectiveness and possibility of our method. Section 5 concludes and offers future works.

2 Formalization

2.1 Service Area

A road network in a service area is given by a graph G which consists of nodes N and edges E as Equation 1. The nodes represent intersections and the edges represent road segments between intersections. For simplicity, we do not consider one-way traffic and traffic jam. We denote the distance between n and n' as $d(n, n')$.

$$G = (N, E), N = \{n_1, n_2, ...\}, E = \{e(n, n') \,|\, n, n' \in N\} \tag{1}$$

There are h stations where users get on/off cars in a service area. The stations are corresponded to a subset of nodes (Equation (2)).

$$S = \{s_1, s_2, ..., s_h\} \in N \tag{2}$$

All users aim to move from a node to another node. And all users select n_i as a start node or a goal node with a choice probability: p_i. A probability p_i is given by Equation(3) which contains a weight of choice probability: w_i. A weight w_i of choice probability is set from 0 to 1 randamly.

$$p_i = \frac{w_i}{\sum w_k} \tag{3}$$

2.2 Station

A station s_i is given by Equation (4), where V_i is a set of parked vehicles, R_i is a list of reservations, and α_i is a optimum number of parked vehicles. The optimum number α_i of parking vehicles is obtained by the number of reservations at s_i: $|R_i|$, the number of reservations at all the stations: $|R_{all}|$, and the number of parked vehicles at all the stations which is given by Equation (5). For simplicity

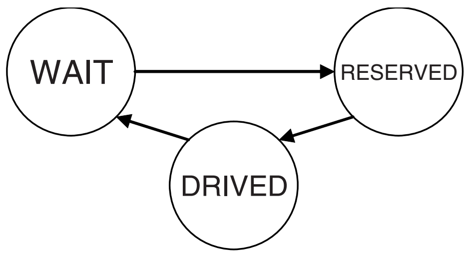


Fig. 1. State transition of a vehicle

of problems, we do not consider a limit of the number of parked vehicles i.e, it is possible that infinite vehicles park at a station.

$$s_i = (V_i, R_i, \alpha_i) \tag{4}$$

$$|R_{all}| = \sum_{j=0}^{K-1} |R_j|, \alpha_i = |V| \times \frac{|R_i|}{|R_{all}|} \tag{5}$$

2.3 Vehicle

Vehicles are given by V in Equation (6). The traveling speed of vehicles is fixed as q_v. The state transition of a vehicle is shown in Figure 1. In WAIT, a vehicle waits for reservation at a station. A request is given as a pair of ride-on and drop-off stations. If a vehicle received a reservation from a user, the vehicle is reserved for the user and waits for his/her arrival (RESERVED). In RESERVED, the vehicle does not receive other reservations. The user drives the vehicle from the station to his/her drop-off station (DRIVEN). After the driving, the state of the vehicle transits again to WAIT. We assume that β persons can ride on a car at the same time.

$$V = \{v_1, v_2, ..., v_m\} \tag{6}$$

2.4 User

Users are given by U in Equation (7). The walking speed of users is fixed as q_u. A user u_i is given by Equation (8) which contains a reservation: r_i, the number of persons: γ_i, a start node: n_i^s, and a goal node: n_i^g. A user u_i is a group of γ_i persons, but we call just a user in this paper. A reservation r_i is given by Equation (9) which contains a start time: t_i^s, a end time: t_i^e, a station where u_i will ride on: s_i^r, and a station where u_i will drop off: s_i^d. The state transition of a user is shown in Figure 2. In SEARCH, a user u_i decides the ride-on station s_i^r and the drop-off station s_i^d. Here, let S_{wait} be the set of stations where some vehicles are available (in WAIT). The station, which is closest to the start node n_i^s, is selected from S_{wait} as ride-on station s_i^r. And, the station which is closest to the goal node n_i^g is selected from S as the drop-off station s_i^d. Next, the user u_i decides whether they use vehicles or not by the condition $T_i^t \leq T_i^f$. The

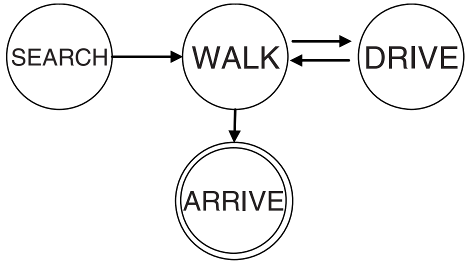


Fig. 2. State transition of a user

travel time for the user u_i by using the system is given by T_i^t which is defined in Equation (10). The travel time for the user u_i by walking is given by T_i^f which is defined in Equation (11). If the condition is satisfied, firstly the user u_i sends the reservation r_i and walks to the ride-on station s_i^r (WALK). Then, the user u_i drives the car to the drop-off station s_i^d (DRIVE). Finally, the user u_i walks to the goal node n_i^g (WALK), and finally arrives at his/her destination (ARRIVE). Otherwise, the user u_i walks to the goal node n_i^g directly by walking (WALK)

$$U = \{u_i, u_2, ...\} \tag{7}$$

$$u_i = (r_i, \gamma_i, n_i^s, n_i^g) \tag{8}$$

$$r_i = \left(t_i^s, t_i^e, s_i^r, s_i^d, v_j\right) \tag{9}$$

$$T_i^t = \frac{d(n_i^s, s_i^r) + d\left(s_i^d, n_i^g\right)}{q_u} + \frac{d\left(s_i^r, s_i^d\right)}{q_c} \tag{10}$$

$$T_i^f = \frac{d(n_i^s, n_i^g)}{q_u} \tag{11}$$

3 Optimization of Vehicle Assignment

The probability with which a user selects a node as a start node or a goal node is not uniform among stations. Moreover, a user can return a vehicle to any stations at any time. It is hard to keep distribution balance of parked vehicles among stations. Disruption of distribution balance causes decreasing convenience of a car sharing system. Therefore, it is necessary to optimize the distribution of idle vehicles. In this paper, we propose a method for assigning the optimum number of using vehicles to users, according to distribution of parked vehicles, in order to assign the number of in/out vehicles between ride-on/drop-off stations. There are three ways of assignment: normal assignment, divided assignment, and combined assignment.

3.1 Way of Assignment

Normal assignment. In normal assignment, a user ($n\,(n \leq \beta)$ persons) rides on one vehicle. As a result, the user subtracts one vehicle from the ride-on station, and adds the vehicle to the drop-off station.

Divided assignment. In divided assignment, a user ($n\,(2 \leq n \leq \beta)$ persons) rides on $m\,(2 \leq m \leq n)$ vehicles with the divided group. As a result, the user subtracts m vehicles from the ride-on station, and adds m vehicles to the drop-off station. Compared with the normal assignment, the divided assignment increases the number of moved vehicles from 1 to m, so that it has advantages to assist "decreasing parked vehicles at a ride-on station" and "increasing parked vehicles at a drop-off station".

Combined assignment. In combined assignment, k user groups (total of $n\,(k \leq n \leq \beta)$ persons) which have the same drop-off station, ride on one vehicle with the combined group. As a result, the users subtract one vehicle from the ride-on station, and add one vehicle to the drop-off station. Compared with the normal assignment, the combined assignment decreases the number of moved vehicles from k to 1, so that it has advantages to prevent "decreasing parked vehicles at a ride-on station" and "increasing parked vehicles at a drop-off station".

3.2 Decision of the Number of Assigning Vehicles

In a station which has excessive vehicles, it is possible to reduce the number of vehicles by assigning a divided ride. On the other hand, in a station which has less vehicles, it is possible to increase the number of the vehicles by assigning a division ride. Thus, it is necessary to decide the number of assigned vehicles depend on distribution balance of parked vehicles. In this paper, decision of the number of assigned vehicles is based on a square residual error sum for the number of parked vehicles and the optimum number of parked vehicles. Residual sum of squares T between the optimum number of parking vehicles α and the number of parking vehicles $|V|$ is shown by Equation (12).

$$T = \sum_{i}^{K} (\alpha_i - |V_i|)^2 \tag{12}$$

All users select the number of using vehicles which minimizes residual sum of squares T. Thus, all users select the number of using vehicles which minimizes residual sum of squares T_{ij} between a ride-on station and drop-off station which is shown by Equation (13).

$$T_{ij} = (\alpha_i - |C_i|)^2 + (\alpha_j - |C_j|)^2 \tag{13}$$

4 Experiments

There are four experimental patterns shown in Table 1. A service area is set to a square (600 × 600 pixels). A road network in the area is set to a grid network (30 × 30), i.e., the length of all road segments is 20 pixels. The service process is repeated until the max time $5.0 \times 10^6 t$. Other parameter setting is shown in Table 2.

First, we report experimental results related to occurrence rate of reservations. The occurrence rate of reservations is set from 1% to 20%. The number of vehicles

Table 1. Experimental pattern

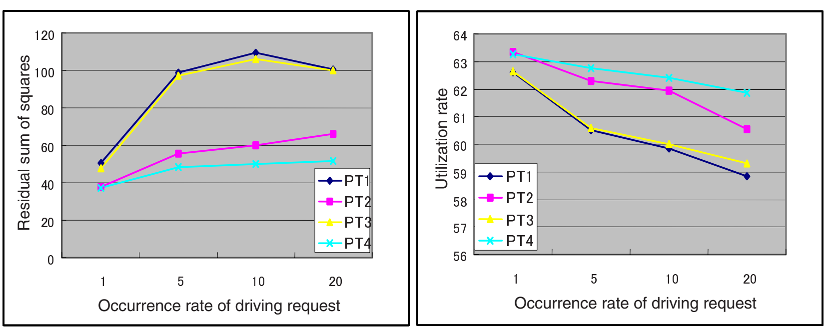
Pattern	Normal assignment	Divided assignment	combined assignment
PT1		—	—
PT2			—
PT3		—	
PT4			

Table 2. Experimental parameter

Parameter	Value
$\|S\|$	20
$\|C\|$	35
$\|q_v\|$	20
$\|q_u\|$	2
γ	2
β	4

is set to a fixed value 100. Figure 3(a) indicates that PT4 could decrease the residual sum of squares compared with PT1. However, PT3 could not decrease the residual sum of squares compared with PT4. This is due to rare selection of combined assignments. It is necessary to assign combined assignment that users have the same drop-off station. As a result, it is thought that combined assignment was not assigned so much. Moreover, Figure 3(b) indicates that PT2, PT3, and PT4 can improve the utilization rate compared with PT1. Altogether to control the number of assigning vehicles, in order to control the number of in/out vehicles at ride-on/drop-off stations improve the utilization rate.

Second, we report experimental results related to the number of vehicles $|V|$. The number of vehicles is set from 40 to 200. The occurrence rate of driving



(a) Residual sum of squares (b) Utilization rate

Fig. 3. Experimental results related to occurrence rate

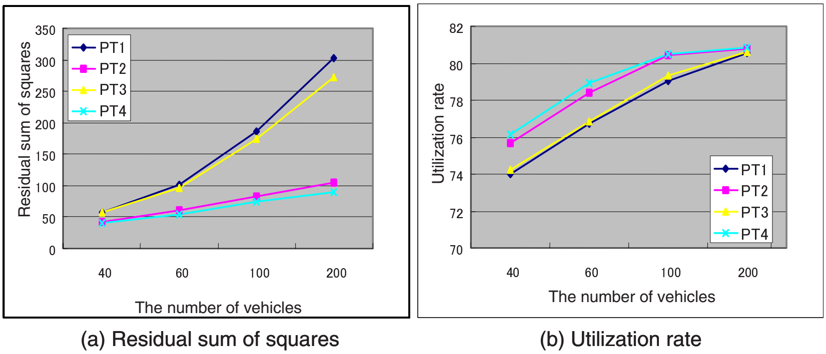


Fig. 4. Experimental results related to the number of vehicles

requests is set to a fixed value 5%. Figure 4(a) indicates that increasing the number of vehicles makes residual sum of squares increase, especially as PT1, PT3: not assigned combined assignments.

5 Conclusion

In this paper, we focus our attention on the one-way type car sharing system. It is hard to keep a distribution balance of parked vehicles among stations in the one-way type, because the one-way type user can return a vehicle at any station. The distribution balance of vehicles is a key problem to be solved for improving convenience of the system. Therefore, we propose a method for optimizing distribution balance of parked vehicles by assigning the optimum number of vehicles to users. The effectiveness of our method is estimated by our computer simulation. The results of the simulation show that our method is effective for one-way car sharing system. In our future work, we must consider incentives for users to behave according to proposed model. In addition, we should perform the simulation by using real city maps.

References

1. Nakashima, H., Kurumatani, K., Itoh, H.: Supporting a society with ubiquitous computing. IPSJ-MGN450904t (2004)
2. Ohta, M., Shinoda, K., Noda, I., Kurumatani, K., Nakashima, H.: Usability of demand-bus in town area. IPSJ-MBL02023033 2002 (2002)
3. Abraham, J.E.: A survey of preferences in carsharing. The Journal of World Transport policy & Practice (2000)
4. Britton, E.: Executive summary in carsharing 2000: Sustainable transport's missing link. The Journal of World Transport Policy & Practice (2000)
5. Mukai, N., Watanabe, T.: Dynamic Location Management for On-Demand Car Sharing System. In: Khosla, R., Howlett, R.J., Jain, L.C. (eds.) KES 2005. LNCS (LNAI), vol. 3681, Springer, Heidelberg (2005)