Applied Energy Symposium 2020: Low carbon cities and urban energy systems
October 10-17, 2020
Paper ID: CUE2020-D-051

Potential taxi ride-sharing analysis based on GPS trajectory: a case of Qingdao

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ABSTRACT

By reducing total travel time and travel distance, taxi ride-sharing is of great significance to decrease urban carbon emissions sourced from ground transport. Efficiency of taxi ride-sharing at metropolitan-wide scale can be challenged by heavy computation in matching multiple ride demands in. In this paper, a fast matching strategy based on time and distance constraints is proposed to filter candidates. Experiment shows that the strategy can reduce the times of candidate matching and improve the searching efficiency. An empirical analysis of potential taxi ride-sharing in two periods of a day (9:00-10:00,21:00-22:00) based on taxi GPS trajectory data in Qingdao shows that when tolerance time of delay time is 5 min, 35% of the total trips can be shared. Total travel time of all trips can be saved by nearly 222 hours and the total travel distance can be reduced by nearly 9200 km. CO, NOx, PM2.5 and fuel consumption can be saved about 6348g, 515g, 10g and 515.2kg during each period, respectively. Our study provides a positive evidence for potential emissions reduction by taxi ride-sharing, so as to support better understanding on low-carbon urban transport service.

Keywords: Taxi GPS trajectory; taxi ride-sharing; matching and filtering strategy

1. *INTRODUCTION*

Carbon emission from urban ground transportation has become an important source of global greenhouse gas (GHG) emission, which poses a severe challenge to the protection of ecological environment and human health[1]. As an important part of urban ground traffic, taxi produces a lot of exhaust emissions while providing convenience for people's travel. By adopting the sequential service mode, traditional taxi only serves one trip at any time (except idle), and then cruises to search for new trips. The one-to-one sequence of service is simple, however, this leads to a lot of cruising time searching for new customers, resulting in high idle emissions[2, 3]; on the other hand, studies showed that people traveled with significant time and space similarity[1, 4, 5]. As shown in Fig.1, although the two travel paths (blue and orange) are not same exactly, however, they are very close geographically. Travel start time are also relatively close. When using the sequential mode, it requires two taxis to provide services respectively. Total travel distance is the sum of the two trajectory distance, however, when using the shared travel mode, these two trips can be served by a single taxi (indicated by a dashed green line). Although delay in departure and arrival times caused by the sharing may be unavoidable (by giving a delay tolerance window Δ), it can greatly reduce the total travel distance and total travel time, which leads to emissions reduction.

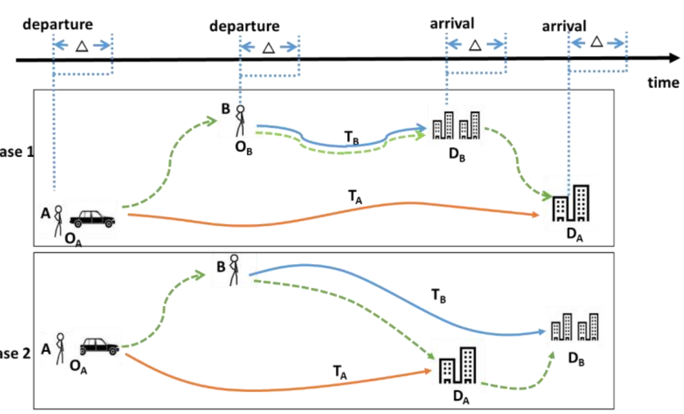


Fig.1 Taxi ride-sharing example. Case1: $O_A \rightarrow O_B \rightarrow D_B \rightarrow D_A$; Case 2: $O_A \rightarrow O_B \rightarrow D_A \rightarrow D_B$

Fig.2 show that how to reduce the total travel distance and total travel time when using ride-sharing strategy.

Fig.2 Taxi ride-sharing example.In every case, the left picture is ride-sharing trip，the right picture is the original two tripCase1:$O_A \rightarrow O_B \rightarrow D_A \rightarrow D_B$ Case 2:$O_A \rightarrow O_B \rightarrow D_B \rightarrow D_A$;

Matching of ride demands effectively is the key of ride-sharing. In practice, it usually targetd to minimum of travel distance or travel time, which can be solved by heuristic searching. In [6], a spatio-temporal index was defined to search for taxi candidates and a fast algorithm for dynamically matching taxi and ride demand was proposed. In [8], the taxi and ride demand were matched by bipartite graph model. Minimum path covering method was used to solve the optimal matching to minimize the total number of taxis. In [9], start and end time of ride were taken as the constraints to construct a rider-sharing network. Maximum of total travel time reduction was adopted as an optimal object and solved by graph maximum matching algorithm. Online optimization of taxi route using greedy strategy was presented in [10]. The existing research has provided us a very good knowledge of feasible solution of taxi ride-sharing. In order to speed up the matching calculation of taxi ride-sharing, a path optimization model was proposed based on specific characteristics of taxi sharing in [11], in which annealing algorithm was adopted to solve the model to minimize operating costs and maximize customer satisfaction. A mathematical model of real-time mass ride-sharing was proposed in [12], it dynamically generated optimal routes according to online demand and taxi location. the algorithm started from greedy distribution, and improved it by constraint optimization. Then returned the high-quality solution quickly, and converged to the optimal distribution with the development of time. This study adopt the graph model proposed in [9] and provides a fast matching strategy for filter candidates effectively. This strategy can improve performance of matching algorithm so as to support large amount of ride-sharing. Empirical analysis of potential taxi ride-sharing in two periods of a day (9:00-10:00,21:00-22:00) based on taxi GPS trajectory data in Qingdao is provided. Our study shows that total travel time and total travel time can be saved greatly by taxi ride-sharing.

2. METHOD

2.1 Method framework

From view of passenger, taxi ride-sharing can be imagined as follows: 1)User sends a ride request to central system, for example via mobile phone app; 2) waits for δ time to receive the system feedback of a ride-sharing option presenting the information of estimated arrival time without sharing and how, due to sharing, the trip might be prolonged by a time up to Δ; 3) user either confirms or denies the presented sharing option. After the k passengers have confirmed their participation, a shared trip is formed and a available taxi is assigned to serve these users. Consider to the complexity of algorithm, in this paper, we only discuss the case of k = 2. When δ is large, more trips can be shared, however, the user experience would be degraded. Therefore, we set δ = 1 min in this paper.

Set $\{T_i = (O_i,D_i,s_i)\}(i = 1,2,...n)$ is a set of ride requests submitted within the δ time, where O_i,D_i are the starting point and end point of travel trip T_i , where s_i is start time of T_i where n is the total number of trips. Arrival time e_i can be estimated by O_i,D_i,s_i of trip T_i. When k = 2, for ∀i,j ∈ n, T_i,T_j can be shared ($s_i \le s_j$) in the two forms illustrated in Fig.1. Rules of each share case are given in Table 1, where Δ is the maximum user's tolerable waiting time. $t(x \rightarrow y)$ is the travel time from x to y. $\max(x,y)$ is the maximum value between x and y. In case 1, rule (1)(2)(3) mean that the time of arrival at a specified starting point or end point should not be later than the original time of arrival at that starting point or end point plus the longest waiting time that the user can endure. If $t(O_i \rightarrow O_j) < s_j - s_i$, it means that when the taxi arrives at O_j from O_i, T_j has not yet started. Therefore, the taxi needs to wait for a while until s_j begins. Rule (4) means that the travel time of the shared trip should be less than the total travel time that the two trips do not share. Similar rules can be observed in Case 2. If both sharing forms are satisfied, the most time-saving form is used for sharing.

Table 1 shared forms and decision rules

Case1	$O_i \rightarrow O_j \rightarrow D_j \rightarrow D_i$
(1)	$s_i + t(O_i \rightarrow O_j) \le s_j + \Delta$
(2)	$s_i + \max(t(O_i \rightarrow O_j), s_j - s_i) + t(O_j \rightarrow D_j) \le e_j + \Delta$
(3)	$s_i + \max(t(O_i \rightarrow O_j), s_j - s_i) + t(O_j \rightarrow D_j) + t(D_j \rightarrow D_i) \le e_i + \Delta$

(4)	$\mathrm{t}(O_i \rightarrow D_i) + \mathrm{t}(O_j \rightarrow D_j) - [\max(t(O_i \rightarrow O_j), s_j - s_i) + t(O_j \rightarrow D_j) + t(D_j \rightarrow D_i)] > 0$
Case2	$O_i \rightarrow O_j \rightarrow D_i \rightarrow D_j$
(1)	$s_i + t(O_i \rightarrow O_j) \leq s_j + \Delta$
(2)	$s_i + \max(t(O_i \rightarrow O_j), s_j - s_i) + t(O_j \rightarrow D_i) \leq e_i + \Delta$
(3)	$s_i + \max(t(O_i \rightarrow O_j), s_j - s_i) + t(O_j \rightarrow D_i) + t(D_i \rightarrow D_j) \leq e_j + \Delta$
(4)	$\mathrm{t}(O_i \rightarrow D_i) + \mathrm{t}(O_j \rightarrow D_j) - [\max(t(O_i \rightarrow O_j), s_j - s_i) + t(O_j \rightarrow D_i) + t(D_i \rightarrow D_j)] > 0$

Due to amount of time-consuming on the rules determination of every two trips in the n trips. Time complexity is $O(n^2)$. For example, there is a set of trips $T = \{T_i\}$ (i = 1, 2,..., n). n is the number of trips. For a trip $T_m \in T$, where $1 \leqslant m \leqslant n$, $\forall T_j \in T - \{T_m\}$, might be a candidate trip. it need to calculate the time when T_j is shared with T_m, and determine whether T_j can be shared with T_m with given time threshold. However, this is very computationally time consuming. Therefore, it is necessary to use simple rules to filter out most of the trips that cannot be shared with T_m, This can reduce the calculation time.

This paper proposes a fast filtering matching strategy. Main idea is to filter out most of the trips that cannot be shared with the current trip according to the time and distance constraints, so as to get a small set of candidate matching trips which can be used in determining the matching rules in table 1. The filtering strategy is detailed in section 2.2.

After the matching is completed, trips are represented by nodes, and two trips which can be shared are linked by an edge. The time saved by two trips is taken as the weight of the edge. Therefore, a shared trip network $G = (V,E,W)$ can be obtained, where $V = \{T_i\}$. A trip may be shared with multiple trips, therefore, for G, it is necessary to find a subset $G' = (V',E',W')$, so that any two edges in E' have no common nodes, and the number of edges or the sum of weight of edges in E' is the maximum. Obviously, the problem can be solved by maximum matching of graph. In this paper, Blossom Algorithm [13] is used to solve the maximum match. Method framework is shown in figure 3.

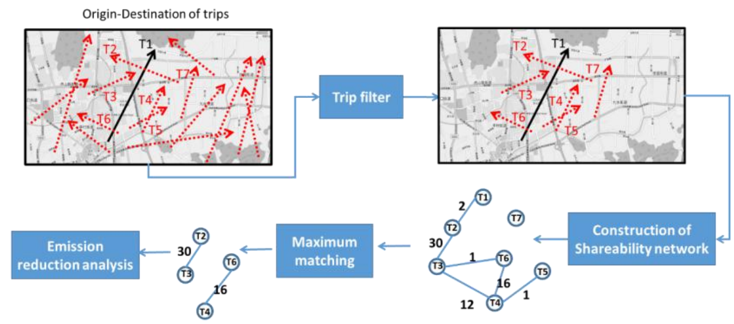


Fig.3 Framework of taxi trips' share method

2.2 trips filtering strategy

There are two factors considering in trips filtering: delay time and detour distance. On one hand, compared with the original time of picking up and picking off, if the time of picking on or picking off after sharing is longer than the threshold time Δ, ride-sharing cannot be established. Δ cannot set to be too large when considering passengers' comfort. On the other hand, when taxis use ride-sharing strategy, if the detour distance is too large, it will not only lead to higher time cost. But it also lead to more pollutant emission from taxis. Therefore, distance between two trips' origin and destination should not be too long.

If two trips do not meet the rule (1) in Table 1, they are not likely to be shared, so rule (1) can be used as a candidate filter. For trips T_i, if T_j can be shared with T_i, the time of arrive D_i must be later than the time of arrive O_j. If the arrival time of the taxi from O_i to O_j is later than the maximum tolerance time of arriving at D_i, the two trips cannot be shared due to violation of rule (3) in Table 1. Therefore, the trip T_j can be filtered out when $s_i + t(O_i \rightarrow O_j) \geq e_i + \Delta$.

In order to realize the calculation of the above two filtering conditions, travel time should be obtained by using road distance and speed. When the starting point and the end point are known, the road distance can be calculated easily, however, the travel speed is related to the road condition, It can be estimated as follows: firstly, a rectangular area is virtually drawn on the map with the straight line between the two points as the diagonal line; Secondly, find all other trips whose origin and destination are both in the rectangular area ,and direction are the same with the trip composed of these diagonal; thirdly, trips are further filtered by travel start time within one hour before and after the starting time of the trip; fourthly, average speed of these trips can be adopted.

In order to avoid the need to calculate the driving speed by using the time constraint strategy, the time constraint is converted into distance constraint. Main idea is that when the detour distance required by ride-sharing trip is too long, it is not only easy to lead to higher time costs after sharing trips, but also leads to more emissions from taxis, so the distance between two trips needs to be limited to prevent taxis from having to go too long. As shown in figure 4, the distance traveled by a taxi for sharing is far greater than the sum of the original distance traveled by the two trips. The two trips obviously cannot be shared. Thus, the following filtering conditions are obtained according to the distance constraint, as shown in Table 2. As long as one of the four rules is met, it can be used as a candidate trip for judging ride-sharing rules, where dist() is used to calculate the direct distance between two points.

Table 2 shows that if the above conditions are not met, the distance of the shared trips is larger than the sum of the original distance of the two trips, which results in longer travel time of ride-sharing trip.

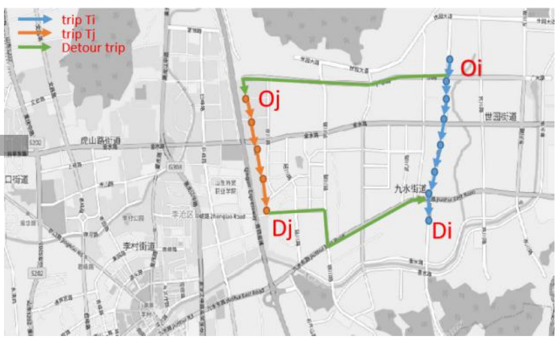


Fig. 4 Distance-based trip filtering conditions

Table 2 distance-based trip filtering criteria

(1)	$\text{dist}(O_j \rightarrow O_i) < dist(O_i \rightarrow D_i)$
(2)	$\text{dist}(O_j \rightarrow D_i) < dist(O_i \rightarrow D_i)$
(3)	$\text{dist}(D_j \rightarrow O_i) < dist(O_i \rightarrow D_i)$
(4)	$\text{dist}(D_j \rightarrow D_i) < dist(O_i \rightarrow D_i)$

3. EMPIRICAL ANALYSIS

3.1 *data introduction and preprocessing*

Taxi trajectories data is provided by Qingdao Hisense Network Technology Co., Ltd, covering about total 8513 taxis in the study area. Information on each taxicab's driver ID, longitude, latitude, status (i.e., 'occupied' or 'vacant'), speed, and timestamp is automatically collected at an average time interval of 30s. Considering 8-year time limit for mandatory scrapping of taxis, without loss of generality, in this study taxi vehicles are regarded to be in compliance with China's Stage IV standards and vehicle technologies are assumed as Passenger Cars and Petrol Small, respectively. GPS trajectory data used in this study were collected on 15/03/2017 (Wednesday). Considering the real driving condition of taxis, unreasonable records of buses are filtered out, such as those with traveling distances shorter than 500m (too short traveling distance is unreasonable), idle or delivery time equals to 0, average travel speed more than 60 km/h (urban speed limit), and a sudden distance deviation over 100m. After these pre-processing steps, there are 7589 taxis with 0.2 million passengers' trips data.

The Qingdao is divided into 200 * 200 grid (the size of each grid is 487m*727m). When calculating the distance between two points in two different squares, the distance between the centre points of the two squares is taken as the distance between the two points which is crawled by AutoNavi API[1.]. The distance between two points in the same grid is determined by the diagonal distance of the grid. Road distance can be calculated in advance through the offline way.

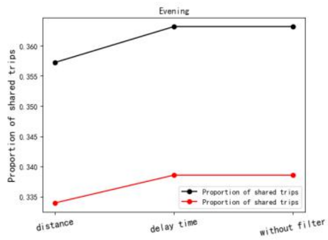
3.2 *experimental analysis*

The data during two time periods (9:00-10:00 and 21:00-22:00) were selected to analyze the effect of taxi ride-sharing. The number of trips shared, the total time saved and the total distance saved are discussed.

(1) Validation of trip filtering strategy

Let Δ = 5 min, the shared results of using the time and distance filtering strategy and the results of not using the filtering strategy are compared as shown in figure 5, it can be observed that the results of using time filtering are basically consistent with the results without using the filtering strategy. The proportion of shared trips is more than 0.34, and the total time saved is more than 219 hours, which indicates that the effect of using time filtering is the best. If distance filtering strategy is used, some sharable trips will be filtered out and some losses will be generated, but the loss is little. The proportion of shared trips of distance filtering is 5 ‰ lower than that without filtering strategy. Considering that the distance-based filtering is more convenient, it is better to use the distance filtering strategy.

[1] https://lbs.amap.com/



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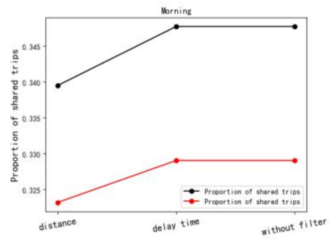

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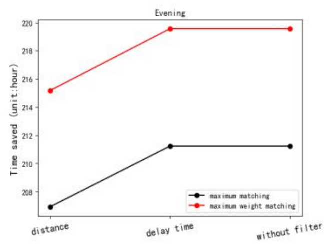

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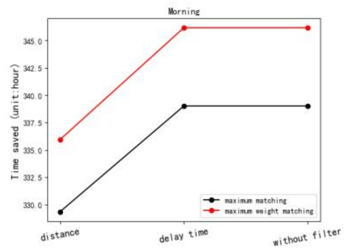
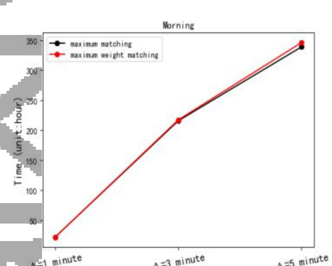


(d)

Fig. 5 Effectiveness analysis of stroke filtering strategy

(2) benefit analysis of taxi ride-sharing

The total number of shared trips, the total time saved and the total mileage saved were calculated by setting Δ = 1 min, 3 min and 5 min respectively. The results are shown in Fig.6. As the delay time Δ increases, the number of shared trips increases rapidly. When Δ = 5 min, the total travel time can be saved about more than 222 hours. The number of shared trips accounts for more than 35% of the original trips. The total travel distance saved reaches 9200 km. The bigger the Δ, the better the performance of the sharing has. But when it is too large it would greatly degrade users' experience and ultimately decrease the number of passengers choosing ride-sharing. According to COPERT model, CO, NOx, PM2.5 and fuel consumption can be saved about 6348g, 515g, 10g and 515.2kg during each period, respectively.



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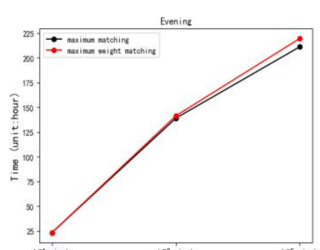

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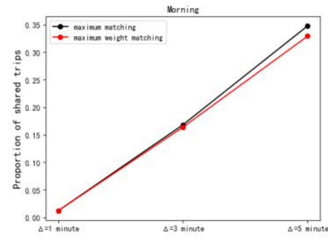

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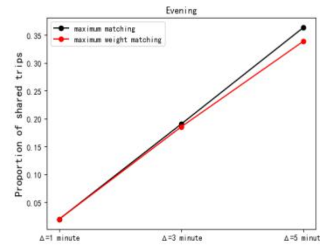

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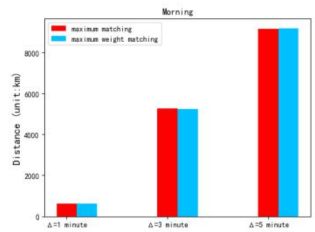

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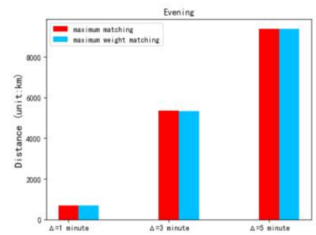

(f)

Fig.6 Change analysis of the number of ride-sharing, total travel time and distance saved when parameter Δ increases

4. CONCLUSION

From the analysis of the experimental results, it can be seen that when the urban taxi adopts the sharing strategy, it can not only reduce the overall taxi carrying time and distance, but also improve the taxi carrying efficiency and reduce the emission of pollutants. After analyzing the results, the fast matching strategy proposed in this paper has achieved good results in solving the problem of large amount of calculation in the taxi trip sharing matching method. Compared with the situation without using the fast screening matching strategy, it effectively reduces the number of candidate matching, and has no significant impact on the sharing efficiency, so it effectively improves the search matching efficiency. Based on the taxi carrying trip data during 9:00-10:00 and 21:00-22:00 of a day in Qingdao, this paper analyzes the feasibility of ride-sharing. It can be seen that when Δ = 5min, the propose of shared trips in each period accounts for 35%, and the saved taxi carrying time are more than 222 hours, and the saved taxi carrying distance is about 9200km. CO, NOx, PM2.5 and fuel consumption can be saved about 6348g, 515g, 10g and 515.2kg during each period, respectively.

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