Transportation Research Part B 103 (2017) 208–226

Contents lists available at ScienceDirect

Transportation Research Part B

journal homepage: www.elsevier.com/locate/trb

Optimal assignment and incentive design in the taxi group ride problem

Xinwu Qian[a], Wenbo Zhang[a], Satish V. Ukkusuri[a,*], Chao Yang[b]

[a] Lyles school of Civil Engineering, Purdue University, West Lafayette, IN 47907, USA
[b] Key Laboratory of Road and Traffic Engineering, Tongji University, Shanghai, 201804, China

ARTICLE INFO

Article history:
Received 27 August 2016
Revised 27 February 2017
Accepted 1 March 2017
Available online 17 March 2017

MSC:
00-01
99-00

Keywords:
Taxi group ride
Optimal assignment
Passenger discount
Driver subsidy
Heuristic algorithm

ABSTRACT

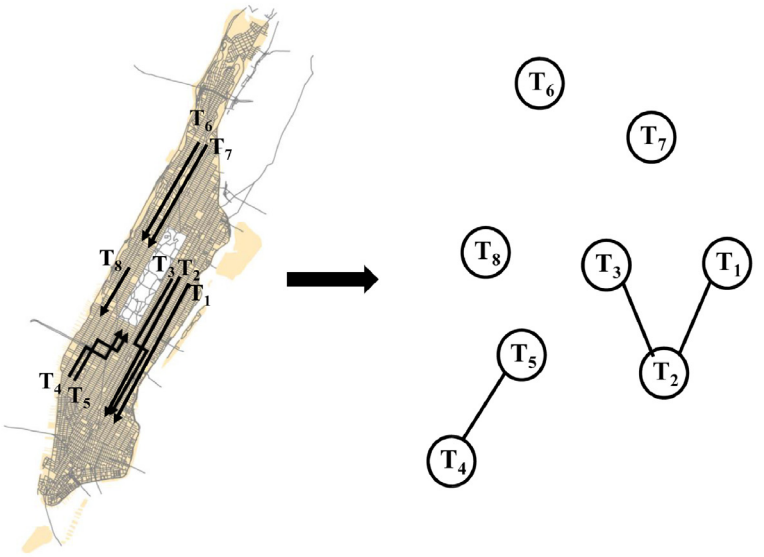
Taxi group ride (TGR) is one popular case of taxi ridesharing, where passenger trips with nearby origins and destinations and similar departure time are grouped into a single ride. The study investigates theoretical and practical aspects of TGR implementation in real world. In particular, two essential problems on operation strategy and policy making of TGR are examined. First, we investigate the optimal assignment of a set of passengers for the sake of maximizing total saved travel miles. Second, we analyze different behaviors of passengers and drivers in participating taxi group rides, and explore the best incentives for TGR in order to maximize efficiency under optimal assignment. The optimal assignment is formulated as an integer linear programming problem and is further converted into an equivalent graph problem. While the problem is NP-hard, efficient algorithms are needed for real-world on-line implementations. We develop an exact algorithm and a heuristic algorithm to solve the TGR problem, and compare the results with a bounded-error greedy algorithm. The numerical experiments suggest that the heuristic algorithm is capable of solving real-world TGR instances efficiently with good solution quality. To explore the best incentives for grouped taxi rides, comprehensive numerical experiments are conducted using taxi trip data from New York City (US), Wuhan (China), and Shenzhen (China). Our numerical results show that over 47% of the total taxi trip mileage may be saved if proper level of incentives are provided and if passengers are matched optimally.

1. Introduction

Taxi is an indispensable mode of transportation to urban travelers due to its great accessibility and convenience in urban areas. By the end of 2014, there were over 13,000 yellow cabs in New York City (NYC), serving more than 450,000 passengers daily (New York City Taxi, & Limousine Commission. (2014)). The taxicab will be most attractive and effective if passengers can access a ride without waiting. However, due to intensive urban activities and improved urban mobility, the taxi supply and demand are often observed to be spatio-temporally unbalanced (Qian et al., 2015). Consequently, passengers may experience excess waiting time or even fail to obtain a ride, and may eventually shift to private vehicles which in return worsens traffic congestion. Merely adding more taxis may mitigate the issue during peak hours, nevertheless, it will

* Corresponding author
E-mail addresses: qian39@purdue.edu (X. Qian), zhan1478@purdue.edu (W. Zhang), sukkusur@purdue.edu (S.V. Ukkusuri), tongjiyc@tongji.edu.cn (C. Yang).

http://dx.doi.org/10.1016/j.trb.2017.03.001
0191-2615/



Trip ID	Pickup Time	Drop off Time
T_1	2015/10/1 08:30:10 AM	2015/10/1 08:53:22 AM
T_2	2015/10/1 08:28:34 AM	2015/10/1 08:50:40 AM
T_3	2015/10/1 08:29:52 AM	2015/10/1 08:51:50 AM
T_4	2015/10/4 06:28:34 PM	2015/10/4 06:54:23 PM
T_5	2015/10/4 06:26:54 PM	2015/10/4 06:50:31 PM
T_6	2015/10/7 01:28:34 PM	2015/10/7 01:48:33 PM
T_7	2015/10/8 01:23:34 PM	2015/10/8 01:45:17 PM
T_8	2015/10/10 08:15:30 AM	2015/10/10 08:28:26 AM

* Assume each bundle of trips are spatially close enough

Fig. 1. Illustration of TGR in Manhattan, NYC. In the figure, trips T_1, T_2, and T_3 have nearby trip origins, destinations, and departure time (same for trips T_4 and T_5). Consequently, these trips can be grouped into the same ride. On the other hand, trips T_6 and T_7 have different departure date, and there is no matching ride for trip T_8.

also introduce excessive empty trips in the off-peak periods. To overcome this issue, we may still maintain the same supply level, but manage to improve the utilization of taxi fleet using the idea of taxi ridesharing.

The objective of ridesharing is to group together travelers with similar itineraries, of which the most common forms are family trips and work-home trips among co-workers (Chan and Shaheen, 2012). But the ridesharing problem for the profit-driven taxi market is intrinsically different from that of private cars. For instance, many taxi riders pay the margin over public transit for the comfort and privacy, and are unlikely to agree to share their rides with strangers, unless offered with sufficient incentives. Similarly, taxi drivers may expect higher revenue to serve shared rides than serving individual trips. In this work, we focus on a specific form of taxi ridesharing, namely the taxi group ride (TGR). TGR works by grouping passengers into the same ride only if they share similar trip origin, trip destination, and departure time. Fig. 1 presents an illustrative example of TGR in Manhattan, NYC. To facilitate a group ride, passengers may be asked to meet at a designated location (e.g., the geometric center of or a landmark nearby their origins and destinations) to take the ride, and will be dropped at a place which comprises the needs of all people on board

Existing taxi ridesharing literature focuses mainly on taxi pooling problem (Yan et al., 2012; Ma et al., 2013; Santi et al., 2014; Tao and Chen, 2007; Santos and Xavier, 2013, 2015), where optimal pick-up and drop-off sequences and corresponding routes need to be calculated to serve passengers who request the service. Admittedly, such method may win over the TGR in terms of flexibility, nevertheless, it also suffers several critical drawbacks which give many passengers a pause. For example, many popular places in large cities are hard to access due to traffic congestion, one-way streets, and long signal timings. Oftentimes, it may take a few minutes traveling between pick-up (drop-off) locations. This is not considering the waiting time from the arrival of taxicab to the presence of each individual passenger along the pick-up route. For the first (last) passenger of a shared ride, he or she may wait for a long time before the trip actually starts. This also introduces difficulties infare calculation which is usually time and distance based. Moreover, based on our discussion with Uber drivers in Shanghai, they occasionally received new rides for ridesharing when they were serving passengers and driving on expressways, and they had to drive all the way to the next ramp and return for picking up the customer. These issues suggest that taxi ridesharing may be better suited for suburban areas. On the contrary, TGR has more restrictions on time and location of potential passengers, but it does not suffer any of the practical issues above. Consequently, it can be implemented directly in urban areas with high travel demand, and may be potentially more effective compared with conventional ridesharing strategies. This is the first motivation of the study.

Another motivation of the study is the potential passenger demand for TGR service, based on our data analysis of combinable trips and real world evidence of the potential for the grouping of trips. We first analyzed the 2013 NYC taxi trip