Computers, Environment and Urban Systems xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Computers, Environment and Urban Systems

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

Understanding the effects of taxi ride-sharing — A case study of Singapore

Yazhe Wang*, Baihua Zheng, Ee-Peng Lim

School of Information Systems, Singapore Management University, 178902, Singapore

ABSTRACT

This paper studies the effects of ride-sharing among those calling on taxis in Singapore for similar origin and destination pairs at nearly the same time of day. It proposes a simple yet practical framework for taxi ride-sharing and scheduling, to reduce waiting times and travel times during peak demand periods. The solution method helps taxi users save money while helping taxi drivers serve multiple requests per day, thus increasing their earnings. A comprehensive simulation study is conducted, based on real taxi booking data for the city of Singapore, to evaluate the effect of various factors of the ride-sharing practice, e.g., waiting time, extra travel time, and taxi fare reduction. The results demonstrate that ride-sharing could serve 20%–25% more taxi booking requests and reduce traveler waiting time during peak hours. It also indicates that there is a reduction in travel distance of approximately 2–3 km per taxi trip on average, which is approximately 20%–30% of the average ride distance.

1. Introduction

Taxis provide flexible point-to-point service to the general public. They are a vital element of a city public transport system. In a modern metropolis like Singapore, there are approximately 28,000 taxis and 99,000 licensed taxi drivers, providing more than 1 million taxi trips daily according to the statistics of the Singapore Land Transport Authority (the regulatory agency for land transportation)[1]. Despite the large number of taxis, people still struggle to hail a taxi, especially during peak hours. Fig. 1 shows the temporal distribution of taxi booking requests and the booking success rate for a normal working day in Singapore from a very popular taxi booking app, GrabTaxi[2]. The figure shows that the booking success rate is extremely low during peak hours, e.g., less than 50% of the bookings are successful during the morning peak at 8 am.

With the newly emerging concept of “sharing economies”, ride-sharing represents an important opportunity to satisfy people's increasing travel demands without increasing the number of vehicles (Cohen & Munoz, 2016). Traditionally, ride-sharing/carpooling is mainly prearranged among a small group of travelers with the same origin and/or destination, e.g., an airport. With today's rapid deployment of geo-locating smartphones and mobile networks, large-scale and real-time ride-sharing has become more and more popular. Several mobile apps, e.g., Lyft, Avego, and Zimride, have been developed for private carpooling. They match private car drivers who have fixed trip schedules with riders who have similar demands. Moreover, some recent research works (Ma, Zheng, & Wolfson, 2013; Shemshadi, Sheng, & Zhang, 2014) have discussed efficient scheduling algorithms for real-time taxi ride-sharing. The shared taxi service can pick up other travelers before dropping off the current traveler(s), therefore, accommodate multiple travelers with different origins and/or destinations at the same time. These algorithms try to efficiently assign the most convenient taxis to ad hoc bookings that are along their routes and plan the optimal route schedule to reduce the total travel distance. They provide service quality constraints to minimize traveler discomfort based on the waiting time and service delays caused by detours.

Although the existing works (Alonso-Mora, Samaranayake, Wallar, Frazzoli, & Rus, 2017; Huang, Bastani, Jin, & Wang, 2014; Ma et al., 2013; Ma, Zheng, & Wolfson, 2015; Shemshadi et al., 2014) enable ride-sharing to a certain degree, they are not very practical because of the following reasons. 1) Some algorithms depend on very complicated index structures with relatively high implementation and maintenance costs (Alonso-Mora et al., 2017; Huang et al., 2014). 2) Many algorithms may cause discomfort to travelers because they may force taxis to constantly change travel routes and receive new, additional travelers (Huang et al., 2014; Ma et al., 2013, 2015; Shemshadi et al., 2014). 3) Some algorithms are not taxi-driver-friendly, as drivers are required to strictly follow planned routes, and they need to constantly monitor new incoming pick-up assignments and changes in travel routes, which will disrupt their driving efforts and cause great danger to both drivers and

* Corresponding author.
E-mail address: yzwang@smu.edu.sg (Y. Wang).

[1] http://www.lta.gov.sg/content/ltaweb/en/publications-and-research.html.

[2] The actual booking number is not revealed because of the Non-Disclosure Agreement (NDA) with the Grab company.

https://doi.org/10.1016/j.compenvurbsys.2018.01.006
Received 12 April 2017; Received in revised form 22 December 2017; Accepted 10 January 2018
0198-9715/

Please cite this article as: Wang, y., Computers, Environment and Urban Systems (2018), https://doi.org/10.1016/j.compenvurbsys.2018.01.006

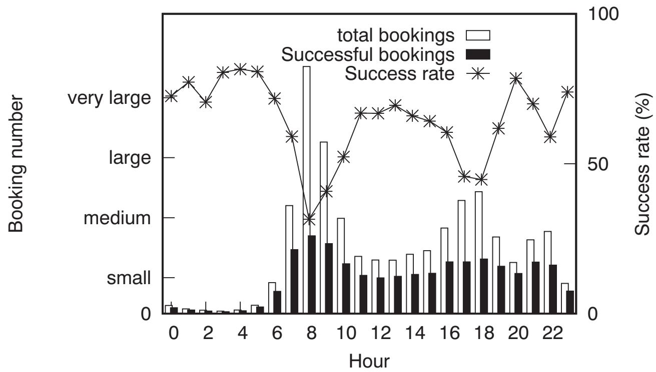

Fig. 1. Average hourly booking statistics for weekdays based on real taxi booking data for Singapore in June 2014.

travelers (Huang et al., 2014; Ma et al., 2013, 2015; Shemshadi et al., 2014). 4) The design and evaluation of the algorithms do not emphasise the economical aspect of taxi ride-sharing (Alonso-Mora et al., 2017; Huang et al., 2014; Ma et al., 2013, 2015; Shemshadi et al., 2014). For example, there is no guaranteed taxi fare reduction for travelers and profit increase for taxi drivers.

This paper seeks to understand the outcome of ride-sharing. A simple yet practical taxi ride-sharing framework is proposed. The framework is very easy to implement and also easy to integrate into current taxi booking apps. It forms a shared trip plan before assigning the trip plan to a taxi. Therefore, travelers are given a fixed trip route/schedule so that they will not feel the discomfort of unexpected changes in travel routes and travel companions. On the other hand, a taxi driver is given a fixed trip plan before starting the journey. Therefore, the driver can focus on driving and does not need to worry about travel route changes, which can greatly improve driving safety. In addition, the framework design considers the economical aspect of taxi ride-sharing by offering travelers a constraint on taxi fare reduction and drivers a shared trip surcharge. Consequently, travelers can choose to share a trip with others only when sharing awards them a satisfying taxi fare reduction (e.g., 20%). At the same time, the framework entitles taxi drivers to charge a fixed shared trip surcharge (e.g., 10% of the normal taxi fare), which serves as an incentive to motivate them to take shared trip jobs.

An extensive simulation study is performed to investigate the outcome of taxi ride-sharing based on real taxi booking data for the city of Singapore. Various factors of the taxi ride-sharing practice are considered, e.g., waiting time, extra travel time, taxi fare reduction, and ride-sharing surcharges determined by the driver. The results demonstrate that ride-sharing could serve 20%–25 % more taxi booking requests and reduce traveler waiting time during peak hours. It effectively address the taxi shortages problem during peak hours. The simulation also indicates a reduction in travel distance of approximately 2 to 3 km per taxi trip on average, which is approximately 20%–30 % of the average ride distance. This suggests that taxi ride-sharing may have the potential to help reduce traffic flow and gas consumption.

2. Related work

There are two main classes of taxi ride-sharing studies: *static taxi ride-sharing* and *dynamic taxi ride-sharing*. Static taxi ride-sharing requires all taxi trips to be known beforehand. Therefore, a globally optimal sharing plan could be derived to maximise the collective benefits of sharing, e.g., cumulative trip length reduction. For instance, Santi et al. (2014) proposed a shareability network to model the spatial and temporal proximity of taxi trips and applied a classical graph algorithm to determine the best trip sharing strategy. Their study revealed that a large number of taxi trips are routinely shareable and that a low level of traveler discomfort in terms of prolonged travel time in big cities (e.g., New York) can be maintained.

Dynamic taxi ride-sharing matches real-time trip requests with running taxis. The trip requests are not known beforehand, and the taxis are allowed to reroute and respond to new trip requests on the fly. Because of the dynamic nature of the problem, the system must be able to respond quickly to new trip requests. Ma et al. (2013, 2015) proposed a T-Share service model with an efficient spatio-temporal taxi index structure. The taxi searching algorithm of T-share follows an incremental approach. It expands the search area from the origin and destination of a trip request step by step until the nearest available taxi is found. Shemshadi et al. (2014) improved the efficiency of the taxi searching algorithm by replacing the incremental search approach with a decremental search approach. Later, Huang et al. (2014) designed an effective kinetic tree algorithm to serve dynamic requests with guaranteed service quality (i.e., pick-up and drop-off time delay). Given a trip request and a candidate taxi, the algorithm finds the best way to accommodate the trip in the current route plan of the candidate taxi. Both ride-sharing algorithms discussed above rely on a very complicated index structure that incurs a high maintenance cost. In addition, the success of the algorithms requires all taxis in the system to strictly follow the complicated and dynamic travel plan at all times, which is highly unrealistic in real-world scenarios. In terms of the effect of taxi ride-sharing, both methods only consider the pick-up and drop-off time delay as the impact factors. In the real world, there are many other factors that can affect the taxi ride-sharing experience, for example, travelers' discomfort due to unexpected changes in trip routes and trip companions, travelers' incentive in the form of reduced taxi fare, and taxi drivers' incentive in the form of increased profit. This paper proposes a more practical taxi ride-sharing framework that relies on a simple scheduling protocol and easy-to-maintain data structure. It considers more practical factors, such as minimizing travelers' discomfort due to unexpected changes in trip routes and trip companions, and economical factors for both travelers and taxi drivers.

Recently, Alonso-Mora et al. (2017) proposed a dynamic trip sharing algorithm based on the request-trip-vehicle shareability graph (RTV-graph). It computes all possible combinations of trips that could be accomplished using one shared vehicle and the vehicles that can serve them. Then, an integer linear assignment problem is solved to find the optimal assignment of vehicles to trips. It relies on a precomputed static shortest path and travel time look-up table to compute the RTV-graph efficiently. However, in the real world, the vehicle travel time in an urban road network is hardly static. Differently, the framework in this paper can incorporate real-time traffic conditions; thus, it is more practical. Gidofalvi, Pedersen, Risch, and Zeitler (2008) designed a trip grouping algorithm for dynamic ride-sharing. It assumes that trip requests are queued to be scheduled at a certain time. Then, it groups "close-by" requests as a rider group, which can be served by a taxi using some heuristics, for example, expiration time, estimated combination saving, and greedy grouping. It utilises space partitioning and parallelisation to optimise the algorithm performance. However, this heuristic-based algorithm does not guarantee any of the waiting time and cost constraints ensured in previous works.

There are recent works on applying ride-sharing to shared autonomous vehicles (SAVs) (Fagnant & Kockelman, 2016; Levin, Kockelman, Boyles, & Li, 2017). The framework proposed in this paper is readily applicable to scheduling SAV fleets. However, some of the benefits of the framework may not be very obvious when applied to SAV fleets, e.g., the benefit of avoiding frequent updating of driving routes on the fly. Unlike human drivers, SAVs can strictly follow the scheduled routes and will not be distracted by frequent route updates during driving. This paper implements another ride-sharing strategy that is similar to the ones proposed for SAV ride-sharing (Fagnant & Kockelman, 2016); it allows a vehicle to change