Transportation Research Part E 91 (2016) 190–207

Contents lists available at ScienceDirect

Transportation Research Part E

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

Making dynamic ride-sharing work: The impact of driver and rider flexibility

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ARTICLE INFO

Article history:
Received 1 December 2015
Received in revised form 22 April 2016
Accepted 24 April 2016
Available online 6 May 2016

Keywords:
Ride-sharing
Carpooling
Sustainable transportation
Simulation

ABSTRACT

We conduct an extensive computational study to quantify the impact of different types of participants' flexibility on the performance of a single-driver, single-rider ride-sharing system. Our results consistently show that small increases in flexibility, e.g., in terms of desired departure time or maximum detour time, can significantly increase the expected matching rate, especially when the number of trip announcements in the system is small. The insights gained from our study can provide the basis for the design of information campaigns and incentives schemes aimed at increasing the performance and success of ride-sharing systems.

1. Introduction

Ride-sharing allows people with similar itineraries and time schedules to save on travel related expenses such as fuel, tolls, and parking. Ubiquitous mobile technology enables dynamic ride-sharing in which participants announce trips only shortly before their desired departure time. Dynamic ride-sharing provides an attractive alternative to private car usage, because it is more convenient than public transportation but less expensive than a taxi.

Establishing matches on short notice requires a centralized system that automatically and efficiently matches riders and drivers based on their trip information. Several dynamic ride-sharing providers, such as Flinc and Carma, offer such a centralized matching service. Participants announce their trips to the system via a mobile or web app. The system then matches drivers and riders and assists the driver with his trip, i.e., provides navigation information. Flinc, for example, is fully integrated in the NAVIGON app so that drivers can easily offer a ride while navigating to their destination. The system guides a matched driver to the rider's pickup and drop-off location.

Ride-sharing is not only beneficial for the individual participants, but also has important societal benefits. By reducing the number of vehicles needed to satisfy the mobility needs of its participants, ride-sharing can reduce congestion, fuel consumption, and pollution. It also reduces the need for parking space, which is increasingly difficult to find, especially in densely populated urban areas.

Successfully matching riders and drivers on short notice requires a sufficiently large number of participants (Kamar and Horvitz, 2009; Agatz et al., 2011). Several studies and pilot programs have examined the use of incentives to attract more people to a ride-sharing systems in order to reach a critical mass (see e.g. Epperson (2015)). However, few, if any, studies

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http://dx.doi.org/10.1016/j.tre.2016.04.010
1366-5545/

consider the use of incentives to increase the effectiveness of ride-sharing systems by rewarding participants for being more flexible. When a participant accepts to be more flexible in his departure time, for example, it is more likely that a match can be found. To employ incentives that encourage flexibility effectively, a ride-share provider needs to understand when additional flexibility is most beneficial and what type of flexibility is most beneficial for the system. Creating that understanding is the focus of this paper.

The main contributions of this paper can be summarized as follows: (i) We introduce and define three different types of participant flexibility that are relevant in the context of dynamic ride-sharing, i.e., matching flexibility, detour flexibility, and scheduling flexibility; (ii) We quantify the impact of these types of flexibility on system performance by conducting an extensive computational study; and (iii) We investigate the required level of additional flexibility that is required to improve the effectiveness of a ride-share system. While previous studies have looked at some aspects of participant flexibility in isolation, this is the first study to explicitly and extensively investigate the interaction between system density, level of flexibility, and type of flexibility.

We focus on dynamic ride-sharing systems that automatically generate matches between a *single* driver and a *single* rider, since this is the setting that is prevalent in today's market. Our efforts can also be viewed as an important and necessary first step in studying the value of flexibility in more complex ride-sharing systems with multi-rider matches and/or transfers. Our findings are relevant to ride-share providers, to public authorities that are considering to use dynamic ride-sharing to address road congestion, and to academics in this emerging field of research.

A few of the key findings are that (1) when the number of trip announcements in the system is small, participants need to be flexible in their departure times to find a match, (2) the extent to which drivers are willing to make detours is critical to the success of a ride-sharing system, and (3) the flexibility required to be matched can vary significantly for system participants. The insights generated can stimulate and facilitate the design of incentive schemes that encourage and/or compensate participants to accept less desirable matches in order to improve overall system performance. We note that in our numerical experiments, we assume that all announcements for the day are known in advance, which means that the matching rate obtained provides an upper bound on the matching rate that can be obtained in a dynamic setting. Earlier studies (e.g., Agatz et al. (2011)) have shown that because rides are announced shortly before their departure, the upper bound is quite tight and thus that the matching rates should be representative of what can be expected in dynamic settings.

The remainder of this paper is organized as follows. In Section 2, we provide an overview of the related literature. In Section 3, we introduce the workings of a dynamic ride-sharing system, we define the types of participant flexibility, and discuss the potential role of incentives in dynamic ride-sharing systems. In Section 4, we describe the generation of the instances used in our computational study. In Sections 5 and 6, we motivate and discuss the computational experiments conducted and present the results. We conclude with a summary of findings and recommendations in Section 7.

2. Related literature

Experience of practitioners and academics alike suggests that the design and operation of dynamic ride-sharing systems is challenging and requires a thorough understanding of the behavior of such systems in different circumstances. The studies of Kamar and Horvitz (2009), Kleiner et al. (2011), and Agatz et al. (2011) identify important challenges in (dynamic) ride-sharing from an organizational and system-design perspective. They also propose different solution approaches to solve problems related to the matching of riders and drivers and the determination of payments to drivers. Xu et al. (2015a,b) study the interaction between ridesharing and traffic congestion at an aggregate system level. They focus on modeling whether or not travelers will participate in ridesharing given certain congestion conditions and financial incentives.

As a part of a larger study, Agatz et al. (2011) simulate the launching of a real-time ride-sharing application in the Metropolitan Area of Atlanta. They find that such systems have an important potential and that it is theoretically possible to launch and sustain them. However, they also underline that overcoming the launching phase and growing a user base is extremely difficult if users are discouraged by not finding matches and consequently stop announcing trips. They conclude it is important to match as many participants as possible and to provide incentives so that participants continue announcing trips even though they are not always matched.

Kleiner et al. (2011) also highlight the challenge of attaining critical mass in dynamic ride-sharing and provide a solution approach based on a sealed-bid second price auction scheme to mitigate it. Lee and Savelsbergh (2015) and Stiglic et al. (2015) propose different strategies to increase the matching rate of a ride-sharing system and thereby overcome problems related to critical mass. The former propose the use of dedicated drivers to guarantee a high matching rate for the riders, while the latter propose meeting points to allow riders to be picked-up at more convenient locations thereby increasing the matching rate.

Agatz et al. (2011) and Stiglic et al. (2015) also conduct experiments to observe the effects of variations in departure time flexibility, time flexibility of drivers, and time flexibility of riders. The general conclusion is that additional flexibility can have important positive effects on the matching rate, but mostly when initial flexibility is low. Diminishing returns to scale were observed for all types of flexibility. In both studies, these experiments are performed for a single setting and a single density level by examining few different parameter values only.

Several papers investigate shared taxi or ride-sharing services in which multiple riders can be served on a single trip. Since this involves deciding the sequence of the pickups and drop-offs of the riders, it is more challenging computationally