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Agent based model for dynamic ridesharing

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ABSTRACT

Dynamic ridesharing involves a service provider that matches potential drivers and passengers with similar itineraries allowing them to travel together and share the costs. Centralized (binary integer programming) and decentralized (dynamic auction-based multi-agent) optimization algorithms are formulated to match passengers and drivers. Numerical experiments on the decentralized approach provides near optimal solutions for single-driver, single-passenger cases with lower computational burden. The decentralized approach is then extended to accommodate both multi-passenger and multi-driver matches. The results indicate higher user cost savings and vehicle kilometers traveled (VKT) savings when allowing multi-passenger rides. Sensitivity analysis is conducted to test the impact of the service provider commission rate on revenue and system reliability. While short term revenue can be maximized at a commission rate of roughly 50% of each trip's cost, the resulting drop in system reliability would be expected to reduce patronage and revenues in the longer term.

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1. Introduction

Dynamic ridesharing involves a service provider that matches potential drivers and passengers with similar itineraries allowing them to travel together and share the costs. These services are dynamic in nature since users announce their participation at any time by either requesting a ride as a passenger or offering a ride as a driver. Technological advancements such as GPS-enabled smart phones, social networks, data repositories, and the internet have led to the proliferation of ridesharing services such as Flinc [Germany, 2011], Avego [Ireland, United States, and China, 2007], Ville Fluide [France, 2011], Carticipate [United States, 2008], Car2gether [Germany, 2010], Carriva [Germany, 2009], Nuride [United States, 2003], Uber [2009], and Lyft [2012]. These service providers differ in their operating polices such as financial transaction rules, route generation, social networks, and subsidy plans.

Any service provider that aims to popularize ridesharing must provide flexibility, convenience, reliability, and motivation (Agatz et al., 2012). Flexibility is the system's ability to adapt to changes in itineraries and time schedules. Convenience is allowing users to state their preferences such as choice of music. Reliability is achieved through a system with a high matching rate and motivation can be provided through financial and environmental incentives such as parking discounts in addition to the cost savings of sharing a ride. Although there are many factors involved in the success of ridesharing services, optimization of driver–passenger matches is critical. Surveys of Furuhata et al. (2013) and Agatz et al. (2012) both identify service pricing and driver–passenger matching as one of the main challenges in ridesharing. It is therefore imperative to

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investigate shortcomings of former optimization methods to obtain more robust systems of ride-matching. Agatz et al. (2012) present a systematic overview of the relevant optimization models that support dynamic ridesharing. They emphasize that centralized ride-matching optimization methods are not fast enough in realistic-size instances and lack flexibility in devising multi-passenger or multi-driver trips. Agatz et al. (2012) also emphasize the significance of using decentralized ride-matching and effective decomposition approaches in terms of geographic partitioning based on origins/destinations of participants. Such decomposition should allow for more flexible ride-matching structures including multi-driver (where passengers hop between rides) and multi-passenger (with more than one passenger in a vehicle) trips.

In this paper a ride-matching algorithm is presented exploiting a decentralized ridesharing system in which virtual driver–passenger agents evaluate potential matching options. Thereafter, a single-shot first-price Vickrey auction is set up where the virtual driver–passenger agents are matched. Multi-driver and multi-passenger extensions are then added to the model. The objectives of this paper are as follows:

- Identify the strengths and weaknesses of centralized and decentralized ride-matching algorithms.
- Develop a system that overcomes some of the shortcomings of the two methods.
- Incorporate a multi-passenger and a multi-driver matching system in the model to increase the success rate of ridesharing services in matching drivers and passengers.
- Investigate the efficiency of various service provider pricing schemes and the potential impact of each on system reliability and vehicle kilometers travelled (VKT) savings.

The remainder of this paper is structured as follows. A review of the relevant literature of centralized and decentralized ride-matching algorithms is provided in Section 2.

A centralized binary integer program is presented in Section 3 as a benchmark to evaluate the efficiency of the proposed decentralized agent-based model which is presented in Section 4. The multi-passenger multi-driver extensions of the model are presented in Section 5. Sensitivity analysis of the model is presented in Section 6 and conclusions are highlighted in Section 7.

2. Literature review

There are two distinct methods of optimization for the dynamic ridesharing problem: the centralized and the de-centralized solution approach. The fundamental differentiating features of the two approaches lie within the level control in each method. The former uses a single system-wide objective function with all decisions made centrally (Agatz et al., 2011; Ghoseiri et al., 2011; Amey, 2011). The latter is composed of autonomous agents optimizing individual objectives using the available local information perceived from the system. While centralized optimization techniques provide better results they can be computationally cumbersome in realistic-size instances of metropolitan areas where thousands of participants join the system to be matched within minutes. Decentralized optimization agents (Kleiner et al., 2011; Winter and Nittel, 2006; Xing et al., 2009), on the other hand, are of interest because they reduce computation time extensively and provide near optimal results.

2.1. Centralized system optimization

Among previous research on centralized system optimization Ghoseiri et al. (2011) propose a dynamic ride-matching optimization model where multiple/single passengers are matched with multiple/single drivers based on their proximity to the driver's route and compatibility of preferences. A passenger is considered a valid match for a driver if he/she is within walking vicinity of one of the nodes in the driver's route. The proposed binary integer programming model maximizes the total number of assignments.

Agatz et al. (2011) develop a dynamic ride-matching optimization method where passengers and drivers are positioned at two sides of a bi-partite graph. The weight of the edges that link each driver and passenger are computed based on the total VKT savings. The bipartite graph is solved in a rolling horizon format where confirmation of matches is delayed until the last minute and in a greedy nature where matches are confirmed as soon as they are found. Agatz et al. (2011) analyze the optimization frequency and conclude that the greedy algorithm, which is less efficient than rolling horizon, should be optimized less often to allow for accumulation of enough potential participants.

Amey (2011) considers the case of matching one driver with one passenger but allows users to be either a driver or a passenger. The proposed algorithm solves a general network flow problem with side constraints and a heuristic solution is given where feasible pairs are ranked based on potential VKT savings. The algorithm then selects the top best match, discards the two selected users from the rest of the list, and moves on to the next pair until the list is empty.

2.2. Decentralized agent based optimization

Xing et al. (2009) introduce a spontaneous ridesharing system where passenger agents seek potential drivers in the network every two minutes in order to find a ride. Xing et al. (2009) show that ridesharing can reduce travel time in comparison

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