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Ride-matching and routing optimisation: Models and a large neighbourhood search heuristic

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ABSTRACT

This paper considers a ridesharing problem on how to match riders to drivers and how to choose the best routes for vehicles. Unlike the others in the literature, we are concerned with the maximization of the average loading ratio of the entire system. Moreover, we develop a flow-dependent version of the model to characterize the impact of pick-up and drop-off congestion. In another extended model we take into account the riders' individual evaluation on different transportation modes. Due to the large size of the resulting models, we develop a large neighbourhood search algorithm and demonstrate its efficiency.

1. Introduction

Ridesharing refers to a transportation mode in which individual travellers share a vehicle for similar itineraries and time schedules. In essence, ridesharing entails the participation of one or more riders (peer customers) to share a vehicle (typically a car) together with the driver (peer provider) when travelling from start points to destinations. The benefits of the ridesharing mode include the split of travelling costs such as gas, toll, and parking fees among individual travellers, and the reduction of congestion and pollution to the public. Despite these benefits, the ridesharing mode is still not a regular transportation alternative, due to the lack of efficient methods to coordinate itineraries and schedules. In the recent decades, technological advances including the global positioning systems, the mobile internet, and social networking create the "critical mass" for the potential prevalence of ridesharing. With the advance of these technologies, a number of matching agencies emerged to provide diverse ridesharing services to travellers. This is mainly stimulated from the development of various ridesharing platforms that create a "pool" for connecting peer riders' travelling demands and peer drivers' services. For instance in China, which has some of the most congested cities in the world, a leading internet firm Tencent uses its ridesharing app, Didi Dache (Honk Honk Taxi), as a strategic tool for the ridesharing market penetration.

Along with this trend multiple decision making problems have emerged, most of which are concerned with the development and optimisation of driver-rider matching. One of the most extensive surveys on the state of the ridesharing systems and the future directions was provided by Furuhata et al. (2013), who pointed out that the rider matching is one of the main challenges. In Furuhata et al. (2013), the authors investigated and classified a set of representative matching agencies, and identified two main taxonomic criteria for ridesharing systems: *primary search criteria* and *target market*. With the aid of the information technologies, *trip planning* becomes one of the common and main functions of matching agencies to support matching between drivers and riders. Each of the drivers and riders lists their offers and requests for ridesharing. while the active matching tries to find potential partners. One of the key issues in a ridesharing platform is how to optimise the success rate of ride-matching with a reasonable notice period. The core in

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the solution of this issue is to devise a matching algorithm that can recommend a driver with the most appropriate riders in align with his or her itinerary and time schedule. Its aim is to enhance the ridesharing efficiency and keep the willingness of drivers to participating in ridesharing, so as to maximize the seat utilization in the vehicles with tolerable impacts on drivers' travelling routes and time schedules. Instead of peer-to-peer communication, ridesharing platforms have their scale advantages and computational advances in providing tremendous matching options between the drivers and riders. A "smarter" solution from the whole ridesharing system's perspective is usually superior to the matching activities conducted by a driver and several riders themselves in both economic and time efficiencies.

The most recent review on the ride-matching optimisation problems was undertaken by Agatz et al. (2012). These problems consider how to determine the routes and schedules of the vehicles (including how to assign riders to drivers) in the presence of conflicting objectives, such as maximizing the number of serviced riders, minimizing the operating cost or minimizing the rider inconvenience. Given these objectives, most of the ridesharing systems prefer to give drivers sufficient time flexibility so that they may be willing to provide rides to several riders along their itineraries either one after another or simultaneously for a portion of time. By doing so, the system makes the effort to achieve ridesharing as many as possible. The value of a ridesharing plan is measured by the combination of the gain to riders due to cost savings and the loss to drivers due to additional travelling time. The above facts show that the decision process in ridesharing systems is similar to dial-a-ride problems/models (DARP). One of the important differences is that in a dial-a-ride system all vehicles typically operate out of one or more depot locations, whereas in a ridesharing system each driver may have a unique origin–destination (OD) pair (see Agatz et al., 2012). Since the riders are usually independent or partially independent in these systems, they are not obligated to accept ridesharing arrangements that they do not like. Therefore, drivers' route preferences or at least the locations of their origins and destinations need to be accounted for when matching drivers and riders in a ridesharing system. This motivates the research of adapting the existing DARP models for solving the ride-matching optimisation problems. To the best of our knowledge, the first variant of dial-a-ride models for the ride-matching optimisation problems was exploited by Baldacci et al. (2004), who considered a matching problem in a car pooling service organized by a large company to encourage its employees to pick up colleagues while driving to/from work to minimize the number of private cars travelling to/from the company site. In this first attempt, some assumptions in the dial-a-ride problems are reserved, such as identical vehicles, the same terminal for all drivers, and the exclusion of the seat utilization in the objective. The proposed model and exact algorithms in Baldacci et al. (2004) are adequate to deal with some of the complexities in this real world problem.

In this paper we consider a ride-matching problem and the associated routing of vehicles. We make our contributions from three perspectives. Firstly, unlike the others in the literature, we consider a different objective, which is to maximise the average loading ratio of the vehicles in the whole system. This target reflects the social expectation on the use of ridesharing systems, as a higher ratio means better utilization of the vehicles. Intuitively a higher ratio implies that more riders should be allocated to each driver, which however might result in a situation where the drivers need to travel longer distances to pick-up and drop-off the matching riders, leading instead to a low loading ratio for their itinerary. We propose a non-linear programming model to formulate this problem, which is then transformed to an equivalent integer program.

Secondly, we extend the model to capture the flow-dependent features in real ridesharing systems. Specifically, we take into account the impact of pick-up and drop-off congestions and delays to the system performance. We also make an attempt to include the riders' individual evaluation into the ride-matching process. Indeed, in practice how the drivers and the riders match each other highly depends on their evaluations of ride-matching recommendations. As far as we know, both are the first attempts in the literature and contribute to the mathematical framework of ridesharing by incorporating real behaviours of riders into the optimisation of the system performance.

Finally, to address the complexity introduced to the proposed models, we establish a variant *large neighbourhood search (LNS)* framework to improve the solution efficiency. A new demand removing method and a randomization method for demand reassignment are proposed and integrated into this framework.

The rest of the paper is structured as follow. In Section 2, we review the related works to the models and the heuristic solution methods to ridesharing problems in the literature. In Section 3, we propose a variant DARP model to the ride-matching and routing problem concerned and investigate a linear reformulation of this model. We extend this model to capture flow-dependent features and include riders' individual evaluation into the ride-matching function in Section 4. In Section 5, we develop a solution algorithm within the LNS framework, which is tested in Section 6 to a number of randomly generated problem instances and its performance is compared against the standard solvers. Finally, a conclusive discussion is presented in Section 7.

2. Literature review

In this section, we review the related literature to our work, with the studies on ridesharing, dial-a-ride problems and heuristics being the three main areas.

2.1. Ridesharing

As a rather new transportation mode, one of most important issues that has been well studied in ridesharing is to identify the key properties in ridesharing systems. A comprehensive review on the conditions for a successful ridesharing system can be found in Agatz et al. (2012). In the literature, technological advances in both hardware and software have been recognized as the key enablers for an efficient ridesharing system. In particular, the ubiquity of Internet-enabled mobile devices plays a critical role in practical dynamic ridesharing (Hartmann, 2008; Chan and Shaheen, 2012). Moreover, a sustainable ride sharing system, as argued by Raney