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Stochastic optimization approach for the car placement problem in ridesharing systems

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ABSTRACT

With the increasing fuel prices and the pressure towards greener modes of transportation, ridesharing has emerged as an alternative to private car ownership and public transportation. In this paper, we focus on a common destination ridesharing system which is of interest in large organizations such as companies and government offices. Particularly, such organizations are looking at using company owned vehicles to offer a ridesharing service by which employees carpool to work thus leading to several benefits that include decreasing pressure on on-campus parking spaces, lowering localized on-campus congestion, in addition to offering a greener transportation mode while lowering transportation costs for employees. Based on discussions with our industry partners, optimizing the distribution of limited number of company vehicles while insuring robustness against unlikely vehicle unavailability is of critical importance. Thus in this paper, we present a stochastic mixed integer programming model to optimize the allocation of shared vehicles to employees while taking into account the unforeseen event of vehicle unavailability which would require some participants to take own vehicles or rerouting of existing vehicles. Since solving the proposed model to optimality is computationally challenging for problems of large sizes, we also propose a heuristic that is capable of finding good quality solutions in limited computational time. The proposed model and heuristic are tested on several instances of varying sizes showing the computational performance. Finally, a test case based on the city of Rome, Italy is presented and insights related to vehicle distribution and travel time savings are discussed.

1. Introduction

Carpooling, also known as car-sharing or ride-sharing, is a transportation model whereby, car drivers traveling towards a destination, pick up and drop off other passengers traveling towards the same destination or traveling on the same route. This mode of transportation is an important alternative to private car ownership and public transportation systems.

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While private car ownership provides significant comfort and flexibility, it is very demanding on natural resources and is a major reason for congestion and traffic delays. For instance in the United States (U.S.), the number of daily commuters is very high. According to the U.S. Census Bureau there are approximately 130 million commuters with 86% of them using a car, a truck, or a van (U.S. Department of Commerce, Census Bureau, 2014). The majority of the nation's workers (76%) drive alone for an average of 25 min to get to work every day, and less than 10% carpool (McKenzie, 2014). Besides congestion, an increased number of private cars also creates parking problems as cars are parked the majority of the time and when they are operational, they carry only a portion of their payload. Apart from being under-utilized and extremely wasteful, private cars are a leading cause for localized pollution.

Carpooling de-congests roads and relaxes the pressure on parking spaces. It also reduces fuel consumption by increasing the payload, thereby reducing emissions. Despite such obvious advantages, the uptake of carpooling has not measured up to the expectations mainly due to the fact that traditional carpooling imposes several constraints on the personal freedoms of passengers and due to the complications faced in organizing and maintaining the service under dynamically changing travel patterns.

Over last decade, technological developments in the field of communication (internet, social networking, smart phones etc.) have enabled modestly successful implementation of organized carpooling. For example Carpooling.com (also known as mitfahrgelegenheit.de in Germany) operates in Europe and similar services like Avego, Zimride and Carticipate operate in the USA. These companies offer available car seats through their websites and smart phone applications. Passengers are then allowed to select the drivers that they want to ride with. This selection is usually based on criteria like origin, destination, route, space, price and some other demographic preferences and attributes.

The optimization of the assignment of passengers to drivers in a global setting with different origins and destinations for participants is rather challenging due to the large size of the problem. However, there are several cases where trips are made by individuals to a common destination and are often repeated on daily basis. Particularly, for carpooling to be more widely adopted, many large companies and universities have already created centralized systems that encourage employees and students to organize shared rides when driving to work. Such carpooling services collect the information from potential drivers (with cars) and interested participants beforehand, and then solve problem of assigning the participants to the cars. The main advantage for such centralized systems resides in the fact that individuals that travel to the same destination such as a company or a university typically have common demographics, interests, and repeated travel patterns which make the carpools more homogeneous and hence more desirable for participants.

Carpooling services that are supported by large companies tend to offer many incentives such as providing emergency taxi services or reimbursements for employees whose assigned driver has left earlier because of an emergency. However, they also add some constraints like requiring a minimum number of employees to form a pool, arrival time to work, etc. Such requirements may add extra constraints to the carpooling problem.

In this paper, we focus on the car placement problem for the optimal design of a carpooling scheme. The problem deals with finding the optimal set of individuals that should be given cars to be used in a shared transportation system. In fact, the car placement problem is based on a collaboration with an industry partner that intends to distribute vehicles to a number of employees to use them to carpool to work and thus the interest in finding the optimal individuals that should be given a vehicle in order to create the most efficient carpooling system. In particular, the industry partner encourages the car drivers to participate in the system by giving them an upgraded high end company vehicle. The other participants that are assigned to the shared vehicles are encouraged to participate in the system by receiving a guarantee for a free taxi ride in the event where the vehicle that they are assigned to does not pick them up. This may be due to the unlikely event of vehicle breakdown or in the event where the vehicle driver is not available as initially scheduled. Thus quality of service is an important aspect of the discussed ridesharing system, and hence we propose a stochastic optimization model which accounts for the possibility that some of the shared vehicles might potentially not be available due to relatively rare events such as a vehicle breakdown or the non-frequent deviation from the travel time windows. Furthermore, the aim is to answer questions related to the dimensioning of the system such as

- What is the minimum number of vehicles that is needed?
- In which areas should shared vehicles be located?
- What is the tradeoff between the number of available vehicles and the savings in travel time?

The contributions of the paper are: (a) a stochastic optimization model for the car placement problem; (b) a heuristic that can find solutions for large scale instances of the problem in limited computational time; (c) extensive computational testing that evaluate the performance of the proposed algorithms.

Following this introductory section, the rest of this report is organized as follows. An extensive literature review on carpooling systems is presented in Section 2. The stochastic optimization formulation of the car placement problem is introduced in Section 3 and details of the proposed heuristic are discussed in Section 4. Extensive computational results that evaluate the proposed approaches are presented in Section 5. Finally Section 6 concludes and highlights future research directions.