Expert Systems with Applications 42 (2015) 6728–6737

Contents lists available at ScienceDirect

Expert Systems with Applications

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

Taxi and Ride Sharing: A Dynamic Dial-a-Ride Problem with Money as an Incentive

Douglas O. Santos, Eduardo C. Xavier *

Institute of Computing, University of Campinas, 13083-852 Campinas, Brazil

ARTICLE INFO

Article history:
Available online 1 May 2015

Keywords:
Taxi-sharing
Ride-sharing
Dial-a-Ride
Heuristics
GRASP

ABSTRACT

This paper deals with a combinatorial optimization problem that models situations of both dynamic ride-sharing and taxi-sharing. Passengers who want to share a taxi or a ride, use an app to specify their current location, destination and further information such as the earliest departure time, the latest arrival time and the maximum cost they are willing to pay for the ride. Car owners also specify their origin, destination, the leaving time and the maximum accepted delay. Taxi drivers report their location and the time they will start and end the service. All drivers need to define a price per kilometer. The problem is to compute routes, matching requests to vehicles in such a way that ride-sharing is allowed as long as some restrictions are satisfied, such as: the capacity of the vehicle, maximum trip cost of each passenger and maximum delay. The problem is dynamic since new requests arrive on-line and routes can be modified in order to attend them. To solve this dynamic problem, the day is divided in time periods. For each period, an instance of a static problem is created and solved by a greedy randomized adaptive search procedure (GRASP). Experiments with instances based on real data were made to evaluate the heuristics and the proposed method. In our simulations with taxis, passengers paid, on average, almost 30% less than they would pay on private rides.

1. Introduction

The Dial-a-Ride problem is a well known problem in the literature, see Cordeau and Laporte (2007), and we study in this paper a version of this problem that models situations of both ride-sharing and taxi-sharing where people would be willing to share rides if they could save money with that. We call this problem by Dynamic Dial-a-Ride Problem with Money as an Incentive (DARP-M).

Ride-sharing is important for the sustainable development. According to Edenhofer et al. (2014), greenhouse gas emissions from the transport sector have more than doubled since 1970, and have increased at a faster rate than any other energy end-use sector, being responsible for approximately 23% of the total of energy-related CO_2 emissions. Ride-sharing may also reduce the traffic congestion which is a serious problem in metropolitan areas. Moreover, it directly benefits people, reducing the costs with transportation and the waiting time to get a ride or a taxi, because sometimes, the supply of vehicles is not enough for the big demand of passengers.

We consider the existence of a framework that allows users to share taxis and their own cars. The framework consists of two components:

- An app used by passengers to specify source and destination, time to be served, maximum time to be delivered, number of people, and how much they are willing to pay for the ride (in case of a taxi ride this should be the taxi cost of a sole trip). The app is also used by car owners and taxi drivers, who need to specify the following: source, destination, leaving time, maximum allowable time to be at destination, price per kilometer and the vehicle capacity.
- A server that receives all information, on demand, and matches vehicles to requests, computing routes for each vehicle.

The goal of this paper is to model a realistic situation of dynamic ride-sharing as a combinatorial optimization problem, and also to propose a method to solve the problem in large scale.

We consider ride-sharing and taxi-sharing as a unique problem, modeled in the following manner: at each instant of time, there is a set of passengers needing to travel from a source to a destination point, and there is a set of vehicles, each one having a source and a destination. Passengers have constraints that need to be considered. The constraints are: an earliest departure time, a latest arrival

* Corresponding author.
E-mail addresses: douglasantos@fb.com (D.O. Santos), eduardo@ic.unicamp.br (E.C. Xavier).

http://dx.doi.org/10.1016/j.eswa.2015.04.060
0957-4174/

time, the number of passengers that will travel together and the maximum value they are willing to pay for the ride. Vehicles can also have an earliest departure time and a latest arrival time. They also must have a maximum capacity and a price per kilometer. The ride cost for each passenger must be calculated in a fair way. The cost of each part of the route is divided equally among all passengers aboard. The problem is to compute routes for each vehicle, where each route is a sequence of source and destination points, satisfying all the constraints and maximizing a multi-criteria objective function. The objective function consists of maximizing the number of attended requests and minimizing the total value paid by all passengers. The problem is called Dynamic Dial-a-Ride Problem with Money as an Incentive (DARP-M).

Notice that ride-sharing and taxi-sharing have some differences. In the case of ride-sharing, usually a private car owner has a specific trip route and he can accept to give someone a ride if this person is going to a close location of his final destination. In the case of taxi sharing, the taxi driver does not have a specific route unless it is attending some other passenger. Taxi drivers do not have time restrictions either, while in the case of ride sharing, the private car owner can have very strict time restrictions. Also, the prices for taxis are fixed while in the case of ride-sharing each driver can specify a different charge. Despite some differences, it is possible to see that our model can deal with both problems.

Note that, the framework can impose other constraints, such as the one presented in Santos and Xavier (2013), which uses a social network and allows people to choose if they want to share a ride only with friends or friends of friends; in Tao et al. (2007), people can choose to share only with people of the same sex; in Lalos, Korres, Datsikas, Tombras, and Peppas (2009), there is a central responsible for motoring all vehicles to see if they are following a pre-specified route. Moreover, frameworks presented in the literature can be adapted to consider the DARP-M.

1.1. Related work

There are other works in the literature that deals with ride-sharing problems. Most of them are derived from the Dial-a-Ride Problem, see Cordeau and Laporte (2007), which is a version of the Pickup and Delivery Problem (PDP), see Parragh, Doerner, and Hartl (2008). The main difference between the problem of this work and other ride-sharing problems is the fact that the DARP-M has cost constraints which do not allow people to pay more for a shared ride than they would pay for a private one. In Herbawi and Weber (2012), a problem called ridematching problem with time windows (RMPTW) is presented. RMPTW is very similar to a Dial a Ride Problem (DARP), but with a different objective function and some additional constraints. The proposed method alternates between a genetic algorithm and an insertion heuristic to solve static snapshots of the problem. In Agatz, Erera, Savelsbergh, and Wang (2011), another kind of dynamic ride-sharing problem is presented, but it is a simpler version, as each driver may pass through only one pickup and delivery location. They modeled the problem as a maximum-weight bipartite matching problem and solved it using the optimization software CPLEX. In Ma, Zheng, and Wolfson (2013), a dynamic taxi-sharing problem is defined and the proposed method solves directly the dynamic version using insertion heuristics. A framework is also presented. In Horn (2002), a software system to manage the deployment of a fleet of demand responsive passenger vehicles, including shared taxis, is described. The proposed method solves the problem with insertion heuristics and local searches. A recent survey describing recent advances in the field of dynamic ride-sharing is presented in Agatz, Erera, Savelsbergh, and Wang (2012).

1.2. Our contributions

In this work we study a new variant of the Dial a Ride Problem where cost restrictions must be taken into consideration. This new problem models situations of taxi sharing and ride sharing where people would be interest in participating if they had economic advantages. For that, the problem imposes that shared trips must cost less than what users are willing to pay.

In order to solve the static problem we propose a new GRASP heuristic with path relinking. We performed several tests with variations of the GRASP heuristic, obtaining one that performs much better than our previous heuristic for taxi-sharing presented in Santos and Xavier (2013).

We also consider the dynamic version of the problem. In this case requests are buffered during sometime and then a static version of the problem is constructed and solved using the GRASP heuristic. Some modifications must be made in the heuristic, since the route for a vehicle might have already been set on a previous iteration, and because of that some passengers might have already been served or are still being served. One crucial point to solve the dynamic problem is to compute shortest paths between all source and destination points in a very efficient way. All points are assumed to be in a graph representing the map of a city. In our solution, we used Contraction Hierarchies, see Geisberger, Sanders, Schultes, and Delling (2008), which was hundred of times faster to compute many-to-many shortest paths than a simple approach using Dijkstra shortest-path algorithm.

We made computational experiments to asses the performance of our heuristics, using instances that simulate taxi activities in the city of São Paulo. In order to do that, we used the real graph obtained from Open Street Map.[1] In our simulations, passengers paid, on average, almost 30% less than they would have paid on private rides.

1.3. Text organization

In Section 2, we define the Dial-a-Ride Problem with Money as an Incentive. Its textual description is presented in Section 2.1 and its mathematical model is presented in Section 2.2. This section also shows the proof of NP-hardness (Section 2.3) and DARP-M's dynamic version (Section 2.4). In Section 3, we propose a method to solve the dynamic problem. In Section 3.1, we present GRASP heuristics that solve the static problem and are necessary for the proposed method. Section 4 shows the results of our computational experiments. At last, in Section 5, some conclusions are presented.

2. The Dial-a-Ride Problem with Money as an Incentive

This section describes the optimization problem called Dial-a-Ride Problem with Money as an Incentive (DARP-M). It represents realistic situations of ride-sharing. The problem is general and can be used to represent taxi-sharing or even a situation where there are taxis and car owners, who want to share their vehicles to reduce trip costs. We present the textual description (Section 2.1) and the mathematical model (Section 2.2). We also prove that DARP-M is a NP-Hard problem (Section 2.3) and Section 2.4 shows what changes when the dynamic version is considered.

2.1. Description

The DARP-M receives a set N with n requests of passengers and a set M with m vehicles that are available for ride-sharing.

[1] http://www.openstreetmap.org/