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A distributed VNS algorithm for optimizing dial-a-ride problems in large-scale scenarios

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ABSTRACT

These days, transportation and logistic problems in large cities are demanding smarter transportation services that provide flexibility and adaptability. A possible solution to this arising problem is to compute the best routes for each new scenario. In this problem, known in the literature as the dial-a-ride problem, a number of passengers are transported between pickup and delivery locations trying to minimize the routing costs while respecting a set of prespecified constraints. This problem has been solved in the literature with several approaches from small to medium sized problems. However, few efforts have dealt with large scale problems very common in massive scenarios (big cities or highly-populated regions). In this study, a new distributed algorithm based on the partition of the requests space and the combination of the routes is presented and tested on a set of 24 different scenarios of a large-scale problem (up to 16,000 requests or 32,000 locations) in the city of San Francisco. The results show that, not only the distributed algorithm is able to solve large problem instances that the corresponding sequential algorithm is unable to solve in a reasonable time, but also to have an average improvement of 9% in the smaller problems. The results have been validated by means of statistical procedures proving that the distributed algorithm can be an effective way to solve high dimensional dial-a-ride problems.

1. Introduction

Nowadays, cities are demanding flexible transportation services for the design of modern mobility services, ad hoc logistic and delivering and reactive emergency transportation, to name a few. Traditional (public) transportation has shown its limitations to offer an adaptive system that could, for example, invest more resources in certain areas if a particular event could affect considerably the user transportation demands. On the other hand, the higher economic costs of classic individual transportation services (such as taxi services) make them not affordable in many cases.

Demand-responsive transport (DRT) has appeared as an alternative to traditional services by providing a flexible transport model that can adapt to the dynamic nature of the scheduling of routes based on user's demands. It uses, in general, medium-sized vehicles shared by several requests where the routes of the vehicles are dynamically computed in order to optimize the total cost, client satisfaction, pollution emissions, etc. DRT offers solutions not only for passengers mobility but also in the fields of medical transportation services and logistics (Xu and Huang, 2009).

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The practical application of large-scale DRT services has the challenge to provide efficient solutions to the demands over large cities or areas. In the literature, a transportation problem with these particular characteristics, the dial-a-ride problem (DARP) has previously been studied and analyzed. In the DARP, the objective is to determine the best routing schedule for a group of vehicles to satisfy the transportation requests of a number of customers. Each request consists of a specific pickup (origin) and delivery (destination) locations along with a desired departure or arrival time as well as the number of items (passengers or packages) to be transported. The items have to be transported to their destinations but not necessarily directly since they could share a ride. The problem takes into account the customer's satisfaction, expressed in terms of additional constraints. The DARP can be proven to be NP-hard. The proof is based on the related NP-hard traveling salesman problem with time windows, into which the DARP can be transformed. Solutions for this type of problem have become increasingly popular (Cordeau et al., 2007; Horn, 2002; Xu and Huang, 2009) from the development of ambulatory services for aging people, to shuttle and merchandise transportation services for organizations. However and as far as the authors are concerned, no other study has tried to solve considerably large-scale instances (i.e. >10,000 requests).

In this study, we present a new distributed and parallel variable neighborhood search (VNS) algorithm that is able to solve high dimensional DARPs by dividing the search space into partitions to allow its exploration in parallel while exchanging the information among the computing nodes to improve the optimization of the search process. The VNS is a heuristic optimization algorithm that has been successfully used with similar problems, obtaining competitive results in all the studies (Carrabs et al., 2007; Parragh et al., 2009, 2010). In Muelas et al. (2013) we proposed a VNS algorithm for solving several demanding scenarios in a large city that an on-demand transportation company could face. Several instances from 100 to 1000 requests were studied, in which the proposed algorithm obtained the best overall results. In the study it was shown the importance of the initialization procedure when facing large-scale and demanding scenarios. In fact, for the 1000 requests instances, the quality of the solution generated by the algorithm was completely conditioned by the starting solution, being unable to obtain a feasible solution when this solution was created in a completely random way. However, as will be shown in this work, the complexity of the initialization method used, as well as some of the best initialization procedures of the literature (Diana and Dessouky, 2004; Potvin and Rousseau, 1993), makes them inappropriate to solve large-scale scenarios. Therefore, in this study we propose a new distributed approach that is able to intelligently divide the search space and explore it by means of the aforementioned VNS algorithm in parallel with the purpose of obtaining feasible and optimized solutions in a reasonable period of time.

The remainder of this paper is structured as follows. Section 2 presents an overview of the literature of the DARPs and vehicle routing problems (VRPs). Section 3 defines the main problem and evaluation function. In Section 4 the details of the new proposal are presented. Section 5 describes the experimental scenario in depth. In Section 6 the results obtained are thoroughly analyzed an discussed. Finally, Section 7 contains the concluding remarks obtained from this work.

2. Related work

The DARP belongs to a more general group of problems referred to as vehicle routing problems with pickups and deliveries (VRPPD) where goods are transported with a fleet of vehicles between pickup and delivery locations. This class of problems is divided into two subclasses depending on whether the pickup and delivery locations are paired or not:

- If the pickup and delivery locations are unpaired, each picked up item can be transported to any delivery location. Depending on the number of vehicles used, two subclasses can be identified: pickup and delivery traveling salesman problem (PDTSP) for the single vehicle case and pickup and delivery vehicle routing problem (PDVRP) for the multiple vehicles problem.
- In the opposite case, each pickup item at a specific location must be delivered to its associated delivery destination. Here, we can find the classical pickup and delivery problem (PDP) and the DARP. Both problems deal with the optimization of a number of requests in which each request specifies the number of items that must be transported from an origin to a destination. The main difference between these two problems is that the PDP is focused in transporting goods whereas the DARP deals with the transportation of passengers. This difference is usually expressed by the addition of constraints such as time windows, route duration and ride time violations.

Depending on the nature of the planning process each transportation problem can be identified as static or dynamic. In the static DARP, the objective is to define the routes that are going to attend the requests. In the dynamic problem, a solution of partial routes has been previously constructed (for example by means of a static algorithm) and new requests have to be inserted in real time. In this article the static version of the DARP has been considered.

The DARP has been extensively studied in the literature. The first publications in this area date from the late 1960s and early 1970s (Rebibo, 1974; Wilson et al., 1967, 1971). Since then, several approaches have been studied for solving this problem.

Due to the high computational demand of the exact methods, in particular on large-scale problems, several heuristic methods have been proposed for dealing with the DARP (Borndörfer et al., 1997; Cullen et al., 1981). Metaheuristics are also