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An adaptive large neighborhood search heuristic for dynamic vehicle routing problems☆

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ABSTRACT

The vehicle routing in real-life transportation, distribution and logistics may change with time, especially when there is existing technology that can produce real-time routing data. In this paper, a metaheuristic procedure based on an Adaptive Large Neighborhood Search (ALNS) algorithm is proposed to solve the Dynamic Vehicle Routing Problem (DVRP) with limited vehicles and hard-time windows. The ALNS involves ad hoc destroy/repair heuristics and a periodic perturbation procedure. In addition, an efficient feasibility check has been designed for inserting customer. By conducting several computational experiments with Lackner's benchmark, we show that the present approach can solve real-time problems within a very short time while improving the quality of the solution. The average number of vehicles is smaller than that of existing algorithms, the maximum average error of the vehicle traveling distance is reduced, and the average computation time remains the same.

1. Introduction

The Vehicle Routing Problem (VRP) [1] consists of determining round vehicle trip(s) so that the total cost (e.g. travel time and travel distance) is minimized while ensuring the delivery of different products to customers according to their particular orders. With recent advances in telecommunications and computer hardware, the Dynamic VRP has emerged to address the large amount of real-time monitoring data, such as current vehicle locations, dynamic customer locations and requests. The model can be used to decide on a new route plan to improve service quality and reduce distribution costs. More recently, a number of variants have been investigated and reported. Among them are the dynamic traveling salesman problem [2], the dynamic traveling repairman problem [3], the dynamic dial-a-ride problem [4], and the dynamic pickup and delivery problem [5].

The DVRP is more complex than the classic VRP in that dynamic requests necessitate the decision-making within a tight timeframe based on uncertain information. A good example is the DVRP with Time Windows (DVRPTW), which is used to serve customers within a pre-defined time period. A tabu search algorithm [6] was the first algorithm used on the DVRPTW. Pankratz et al. solved the dynamic pickup and delivery problem with a genetic algorithm [7]. Hong presented

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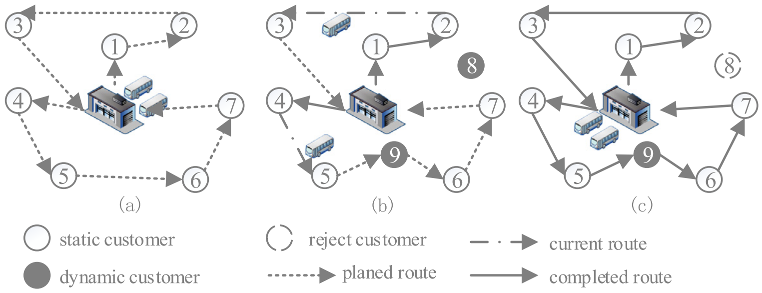

Fig. 1. Illustration of a typical dynamic vehicle routing problem with time windows.

an Improved Large Neighborhood Search (ILNS) algorithm that decomposed the DVRPTW into several static VRPTWs [8]. de Armas and Melián-Batista [9] developed a metaheuristic algorithm for tackling two variants of DVRPTW with several real-world constraints: multiple time windows, customers' priorities and vehicle customer constraints. This study continued in [10], where a General Variable Neighborhood Search (GVNS) algorithm was proposed to solve the DVRPTW as a real-world application, while Saint-Guillain et al. introduced a multi scenario approach in [11]. In recent surveys on DVRPs, Pillac et al. [12] and Ritzinger et al. [13] introduced different problem variations such as deterministic and stochastic DVRPs and commonly used approaches for solving DVRPs. We refer the reader to Psaraftis et al. [14] that provide an overview and a classification of the numerous versions of real-time routing and dispatching problems.

Despite the promising results in solving the DVRPTW, current algorithms often assume that there is no limit on the number of vehicles. They fail to fully capture the reality that there are limited resources, such as vehicles, and manpower. Thus, in real world applications, the DVRPTW is over-constrained, which may lead to conflicting objectives. Still less is known about how to construct a good initial solution and find an optimal solution.

This paper focuses on a more constrained DVRPTW that features heterogeneous vehicles and a soft constraint on their number. A heterogeneous fleet of vehicles for serving customer requests is stationed at a single depot at the beginning of the planning horizon. We present an improved ALNS heuristic for the resolution of the DVRPTW. The problem is decomposed into a series of static VRPTWs. The approach attempts to solve a static problem at each time slice that contains all the known customer requests that have not been visited so far. Therefore, we propose several operators that take advantage of the structure and adapt existing operators for the static VRP. In addition, we apply a 2-opt* local search to perturb the current solution. We report computational results on Lackner's benchmark that are derived from the well-known VRPTW instances of Solomon [15] and compare their performance with existing algorithms such as ILNS [8] and GVNS [10]. In comparison, the average computation time is basically the same, but the average number of vehicles is at least 4.93% better than the existing two methods. The maximum average error of the vehicle traveling distance is 4.63% less than that obtained. The results indicate that our method can solve the DVRPTW with a limited number of vehicles, and return effective solutions in a very short time.

The rest of this paper is organized as follows. In Section 2, we present a mathematical model for the DVRPTW. In Section 3, we describe some heuristic methods from the ALNS algorithm for solving the DVRPTW. The computational results are shown in Section 4. Finally, important conclusions from the results are discussed.

2. Problem description

To better understand the DVRPTW, Fig. 1 illustrates an instance of the DVRPTW, with one central depot, two vehicles, a set of static customers, and a set of customers dynamically requesting during work hours. The house located in the center of the graph is the depot, which is the origin and destination of the vehicles. The white nodes denote the static customers, while black ones denote dynamic customers. Fig. 1(a) presents a static routing scenario with seven customers whose orders were known in advance. To complete their orders, two vehicles are allotted to deliver goods. Fig. 1(b) shows how the old plan is influenced by new orders from customers 8 and 9. In point, the first vehicle is too far from customer 8 to serve her/him in the specified time window, so customer 8 is rejected (denoted by dashed node 8 in Fig. 1(c)). In contrast, the order by customer 9 is acceptable, and the second vehicle can visit her/him just in time. Finally, two vehicles return to the depot after completing all orders.

Formally, a DVRPTW is defined by a complete graph $G=(V, E)$, where V represents a set of vertices consisting of a depot node v_0, and customer nodes, and $E=\{(i, j): i, j\in V, i\neq j\}$ denotes a set of arcs, each of which represents the known travel cost t_{ij} between the node i and j. In formalizing the DVRPTW, customers who placed their orders before planning (i.e. their locations, demands, and time windows are known beforehand) are called static customers and are denoted as V_s. On the other hand, customers whose orders are placed dynamically are dynamic customers, denoted as V_d. Thus, the set $V' := V_s \cup V_s = \{v_1, v_2, \ldots, v_n\}$ represents all customers, and a solution of the DVRPTW is a path (e.g. v_0, v_1, v_2, v_3, v_0) in G that starts from v_0, sequentially visits certain customers (e.g. v_1, v_2, v_3,) and returns to v_0.