A Multi-Trip Vehicle Routing Problem with Time Windows for Pharmaceutical Distribution

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Abstract. This study addresses the multi-trip vehicle routing problem with time windows in the pharmaceutical distribution domain. The objective is to minimize the number of vehicles used to delivery pharmaceutical goods to customers satisfying hard time windows constraints. We propose a two-phase decomposition metaheuristic that combines two iterated local search (ILS) procedures. The metaheuristic is compared with a greedy heuristic and a mathematical model that is effective in terms of solution quality and computing time.

Keywords: Pharmaceutical distribution · Multi-trip vehicle routing problem · Iterated local search

1 Introduction

The vehicle routing problem (VRP) is a significant challenge in the combinatorial optimization area. It concerns the determination of optimized routes for a fleet of vehicles to serve a set of customers. The VRP has several applications in various real-world scenarios such as logistics, goods distribution, and transportation of people (see, e.g., Toth and Vigo [4]).

This paper focuses on a specific VRP variant, the multi-trip vehicle routing problem with time windows (MTVRPTW), inspired by a real-world application at Coopservice Soc.coop.p.A., an Italian service provider. In this scenario, vehicles with different capacities are assigned to different depots to execute routes while satisfying customers' time windows. Each vehicle can perform multiple routes within the same day, all starting and ending at the same depot. The goal is to minimize the number of vehicles required to fulfill customer demands.

To tackle this problem, a two-phase decomposition metaheuristic is proposed. In the first phase, the metaheuristic approach described by Kramer et al. [2] is applied to obtain a set of feasible routes. Since vehicles, in the same day, can perform multiple routes, in the second phase the routes are aggregated to minimize the number of used vehicles. First, the earliest starting time of each route is calculated using the forward time slack procedure by Savelsbergh [3]. Next, we use an ILS procedure that invokes perturbation and local search operators to produce a good-quality solution. The metaheuristic is then compared with a greedy algorithm that assigns routes to vehicles based on the routes' earliest feasible start time. It is also compared with a mixed integer linear programming (MILP) model. Comparisons, performed on real instances provided by the industrial partner, besides other random instances, demonstrate that the proposed metaheuristic performs better than the other approaches.

2 Problem Description

The MTVRPTW is defined on a directed graph $G = (N, A)$, where N denotes the set of nodes and A the set of arcs ($A = \{(i, j) : i, j \in N, i \neq j\}$). Set N is divided into depots (D) and customers (C). Each arc $(i, j) \in A$ is associated with a travel time t_{ij}. Moreover, each node $i \in N$ is associated with a specific hard time window $[e_i,\ l_i]$, representing the earliest and the latest arrival time. Each customer $i \in C$ requires a delivery of demand q_i and a service time s_i. The vehicle fleet V consists of different types, each defined by K_v, where all vehicles $k \in K_v$ are identical in loading capacity and compatibility with customers (e.g., only the smallest vehicles can reach mountainous areas).

A feasible solution must satisfy the following constraints: each route starts and ends at the same depot, satisfying vehicle capacity and covering customers' demands within their time windows; each customer is visited exactly once, receiving all the requested goods; and each vehicle can perform multiple routes per day, without exceeding the total maximum duration of 480 minutes, including a 30-minute loading time at the beginning of each route. The goal is to minimize the number of vehicles needed.

3 Proposed Methodology

We develop a two-phase decomposition approach for solving the MTVRPTW. The first phase tackles the VRPTW, where we generate a set of routes to satisfy the customer demands and operational constraints by using the multi-start ILS by Kramer et al. [2].

The second phase considers the generated routes, aiming to minimize the number of used vehicles in solving the MTVRPTW. To this aim, we define the earliest starting time of each route using the forward time slack procedure proposed by Savelsbergh [3]. We then adopt a greedy algorithm that assigns routes to vehicles, allowing flexibility by adjusting starting times within specified intervals. Aiming to obtain better solutions, we also propose an ILS that iteratively refines the greedy solution through perturbation and local search operators. For comparison purposes, we also present a MILP model. We refer to Cavecchia et al. [1] with comprehensive details on the proposed approaches.

4 Computational Results

We tested the algorithms on a machine equipped with an Intel Xeon Gold at 2.30 GHz. Instances were provided by Coopservice, based on their real activities in Sardinia and Emilia Romagna regions, and ensuring compliance with data privacy regulations. These regions were divided into several areas, each with specific customers, depots, and vehicle types. A total of 28 real instances, covering different working days and areas, were generated. We also produced 120 random instances.

The metaheuristic obtained the best overall performance, improving by 1.64% the results of the greedy algorithm and by 4.50% those of the mathematical model. The mathematical model could not solve to proven optimality the larger instances within a time limit of 600 seconds, and in some cases it failed in producing a feasible solution. The improved solutions have been used by the company to reduce its operational costs.

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