A Simulated Annealing Algorithm for the Vehicle Routing Problem with Drones

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1 Introduction

Civil drones have been used since many years ago in different sectors, e.g., energy, agriculture, surveillance, and emergency response. However, in recent years, many commercial logistic companies such as Amazon, DHL, DPDgroup, etc. have started conducting experiments with the objective of using drones in last-mile logistics, i.e., delivering parcels to the customers [1, 4, 6, 7].

In fact, traditional package delivery systems use conventional transport vehicles, e.g., trucks, cars, or motorcycles for delivering parcels. However, due to growing popularity of e-commerce and importance of fast delivery in satisfaction of the customers, drones attracted attention as an alternative and novel mode of delivery. In comparison to the usual modes of delivery, e.g., trucks, drones might be less reliable but more cost-efficient. Furthermore, drones are considered as a faster mode of delivery as they are not restricted to the road network, traffic jam, and red lights. Consequently, drones are also useful in delivering parcel in areas that are difficult to reach. Finally, drones consume less energy than trucks; hence, drones might be considered as more environment-friendly delivering tools.

Following the practical motivations, many researchers started examining integration of delivery by drones in the classical models, e.g., traveling salesman problem with drone (TSP-D) [1, 2] and vehicle routing problem with drones (VRPD) [6, 7, 9].

Drones are not the sole novelty of technology in parcel delivery. Automated ground vehicles (AGV) or autonomous robots are also considered as a new mode of parcel delivery. Indeed, robots have almost the same advantages as drones except the fact that robots are slower than drones; however, robots are safer and more cost and energy efficient than drones. Consequently, robots might be considered as an even more reliable delivery mode in dense urban areas [3, 5, 8].

In this study, we are interested in a variant of the *Vehicle Routing Problem* (VRP) in which, in addition to trucks, drones with limited capacity are also used to bring parcels to customers. More precisely, the drones assist the trucks in serving customers through so-called *sorties*. This framework that combines trucks and drones is called the *Vehicle Routing Problem with Drones* (VRPD) [7, 9]. Moreover, we investigate the ecological impact of using drones by testing energy consumption of the truck-drone fleet.

2 Description of the problem and the results

We study the *Vehicle Routing Problem with Drones* (VRPD) which aims at routing a fleet of vehicles composed of trucks and drones with the objective of serving a given set of customers in the shortest possible time. This problem can be considered as an extension to the classical *Vehicle Routing Problem* (VRP).

We formulate the VRPD as a *Mixed Integer Linear Program* (MILP), which can be solved by any standard MILP solver. Since VRPD is a challenging optimization problem, the classical tools and commercial solvers, e.g., Gurobi Optimizer or IBM CPLEX, can address only small instances. Consequently, for solving larger instances, we use a two-phase Simulated Annealing (SA) metaheuristic algorithm.

In the first phase of the algorithm, we generate a pool of VRP routes, which are then improved by an SA algorithm. Afterwards, at the second phase of the algorithm, we insert drone sorties. For this purpose, we define and use different drone insertion operators to obtain valid VRPD routes. Then, we apply an SA algorithm to improve the VRPD solutions. Moreover, we use this approach on single- and bi-objective MILP models to generate valid and high-quality routes for the VRPD, where the objective function is composed of either minimizing makespan, or minimizing energy consumption, or both.

According to the computational experiments on the benchmark instances, our algorithm provides high-quality solutions. Moreover, by examining different scenarios, we investigate the impact of using drones on energy consumption of the delivery fleet. The numerical results show important ecological benefits that we can get through using drones.

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