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A large neighbourhood based heuristic for two-echelon routing problems

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ABSTRACT

In this paper, we address two optimisation problems arising in the context of city logistics and two-level transportation systems. The two-echelon vehicle routing problem and the two-echelon location routing problem seek to produce vehicle itineraries to deliver goods to customers, with transits through intermediate facilities. To efficiently solve these problems, we propose a hybrid metaheuristic which combines enumerative local searches with destroy-and-repair principles, as well as some tailored operators to optimise the selections of intermediate facilities. We conduct extensive computational experiments to investigate the contribution of these operators to the search performance, and measure the performance of the method on both problem classes. The proposed algorithm finds the current best known solutions, or better ones, for 95% of the two-echelon vehicle routing problem benchmark instances. Overall, for both problems, it achieves high-quality solutions within short computing times. Finally, for future reference, we resolve inconsistencies between different versions of benchmark instances, document their differences, and provide them all online in a unified format.

1. Introduction

The traffic of vehicles is a major nuisance in densely populated areas. Trucks disturb peoples' well-being by emitting noise and air pollution. As the amount of goods in transit increases, a proper planning of road networks and facility locations becomes critical to mitigate congestion. To face these challenges, algorithmic tools have been developed to optimise city logistics at several levels: considering traffic regulation, itineraries and network design choices. Boosting the efficiency of goods transportation from suppliers to customers presents important challenges for different planning horizons. On the operational level, efficient itineraries must be found for the available vehicles from day to day, e.g., reducing the travelled distance. On a tactical level, the overall fleet size, vehicle dimensions, capacities and characteristics are of interest. Larger trucks are more efficient in terms of cost per shipped quantity, whereas smaller vehicles are more desirable in city centres: they emit less noise, and only need smaller parking spots. Finally, the clever selection of locations for production sites, warehouses, and freight terminals is a typical strategic decision.

In this article, we consider the problem of jointly determining good routes to deliver goods to customers, and at which intermediate facilities a switch from larger trucks to smaller city freighters should happen. This problem is challenging, due to the combination of these two families of combinatorial decisions.

To address this problem, we propose a simple metaheuristic, which combines local and large neighbourhood search with the ruin and recreate principle. The method is conceptually simple and fast, exploiting a limited subset of neighbourhoods in combination with a simple strategy for closing and opening intermediate facilities. We conduct extensive computational experiments on two-echelon vehicle routing problem (2EVRP) and two-echelon location routing problem with single depot (2ELRPSD) instances to investigate the contribution of these operators, and measure the performance of the method on both problem classes. For the

Acronyms: 2EVRP, two-echelon vehicle routing problem; 2ELRP, two-echelon location routing problem; 2ELRPSD, two-echelon location routing problem with single depot; ALNS, adaptive large neighbourhood search; CMA-ES, covariance matrix adaptation evolution strategy; CVRP, capacitated vehicle routing problem; LNS, large neighbourhood search; MDVRP, multi-depot vehicle routing problem; SDVRP, split delivery vehicle routing problem; VNS, variable neighbourhood search; VRP, vehicle routing problem

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2EVRP, this algorithm is able to reach or outperform 95% of the best known solutions. In general, for both problems, high-quality solutions are attained in short computing times. As such, this algorithm will serve as a good basis for future developments on more complex and realistic two-tiered delivery problems.

The paper is organised as follows. The problems are described in Section 2 and an overview of the related literature is given in Section 3. Mathematical formulations are presented in Section 4. Section 5 describes the proposed algorithm. Section 6 reviews current available benchmark instances and examines the performance of the proposed method. Section 7 concludes.

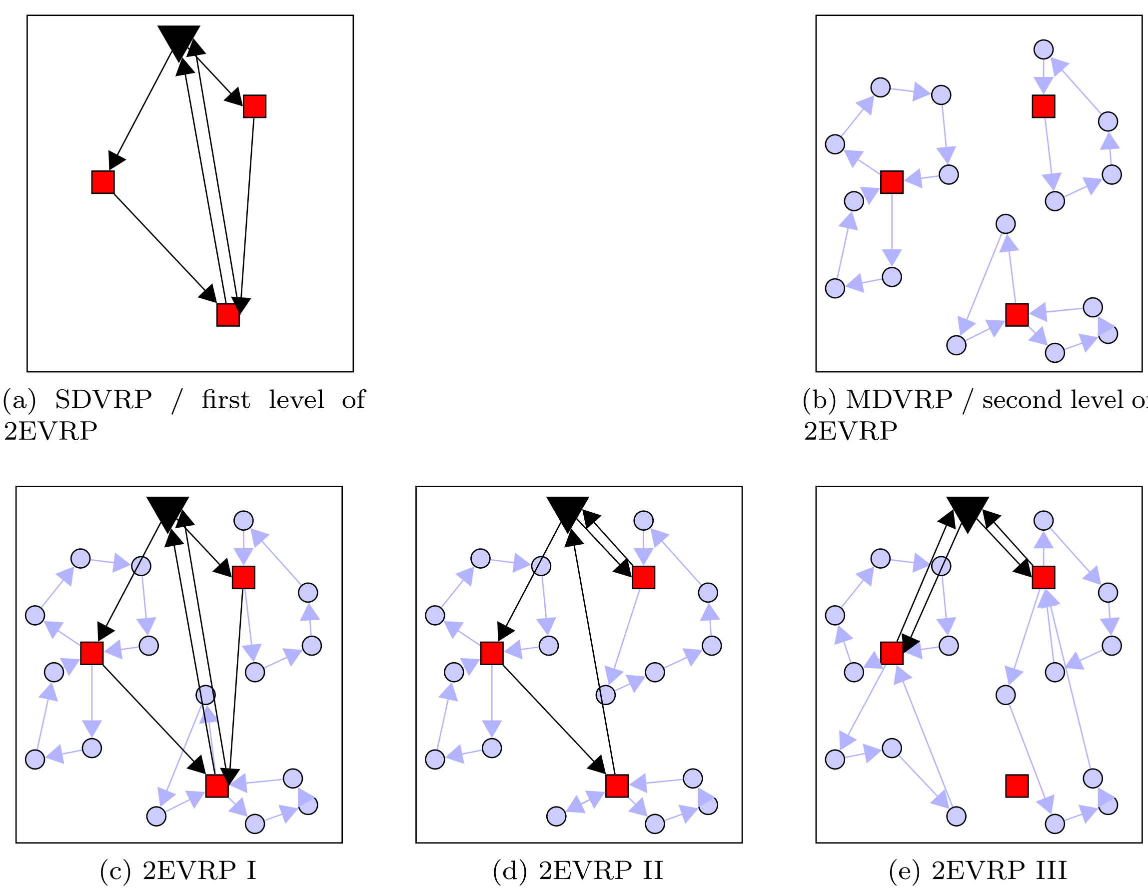
2. Problem description

Vehicle routing problems (VRPs) are a class of combinatorial optimisation problems, which aim to find good itineraries to service a number of customers with a fleet of vehicles. The 2EVRP is a variant of a VRP, which exploits the different advantages of small and large vehicles in an integrated delivery system. The goal is to design an efficient distribution chain, organised in two levels: trucks operate on the first level between a central depot and several selected intermediate distribution facilities, called satellites. The second level also includes the satellites – because both levels are interconnected there – as well as the end-customers. Small city freighters are operated between satellites and customers. The depot supplies sufficient quantities to satisfy all customer demands. The products are directly transferred from trucks to city freighters at satellite locations. These city freighters will perform the deliveries to the final customers. Any shipment or part of shipment has to transit through exactly one satellite, and the final delivery to the customer is done in one block. As such, split deliveries are not allowed for city freighters. The quantity ("demand") of goods shipped to a satellite is not explicitly given, but evaluated as the sum of all customer demands served with city freighters originating from this satellite. Depending on the second level itineraries, split deliveries can occur on the first level since the total quantity needed at one satellite can exceed the capacity of one truck.

Finding good combined decisions for routing and intermediate facility openings is significantly more difficult than in well-studied settings such as the capacitated vehicle routing problem (CVRP). The special case of a 2EVRP with only one satellite can be seen as a VRP [12,24]. The first level of the 2EVRP reduces to a CVRP with split deliveries. The structure of the second level is a multi-depot vehicle routing problem (MDVRP), where the depots correspond to the satellite locations [17]. Those two levels have to be synchronised with each other. The 2EVRP is a generalisation of the classical VRP and is thus NP-hard.

Fig. 1 shows different set-ups for goods distribution. The depot is represented by a triangle, satellites by squares, and customers by circles. Figs. 1a and 1b show graphical representations of a split delivery vehicle routing problem (SDVRP) and a MDVRP respectively. Figs. 1c–e represent feasible solutions for the 2EVRP: with split deliveries occurring at one of the satellites, without split deliveries, and in Fig. 1e a solution where only a subset of satellites is used.

The proposed algorithm has primarily been designed for the 2EVRP, and then tested on the 2ELRPSD, which includes additional tactical decisions. The basic structure of the 2ELRPSD is very similar to the 2EVRP. The main difference is that it corresponds to a more tactical planning since only potential locations for depots or satellites are known and the use of any location results in opening costs. In contrast with the 2EVRP, the fleet size is unbounded, but fixed costs are counted for the use of each vehicle. The classical benchmark sets from the literature include different costs per mile



(a) SDVRP / first level of 2EVRP

(b) MDVRP / second level of 2EVRP

(c) 2EVRP I

(d) 2EVRP II

(e) 2EVRP III

Fig. 1. Subproblems related to the 2EVRP and different solutions depending on which intermediate facilities are used.