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Two-echelon distribution with city hub capacity management

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1 Problem Description

In this paper, we present an innovative distribution scheme aiming at improving the environmental footprint of companies operating in a city logistics context. More specifically, we investigate the daily operations of a parcel delivery company settled in the urban area of Vienna. We propose a two-echelon distribution scheme where goods are not transported directly from their origin (a depot or a warehouse) to their final destination (end customers), but are initially moved into an intermediate platform (a city hub), from where their final distribution is performed. The city hub is located near the city center, close to the final destination of the goods, allowing for a more efficient and environmentally friendly last mile transport.

On the first echelon, trucks transport goods, i.e. parcels, from the depot outside the city to the city hub, where goods are transferred to tricycles, operating on the second echelon between the city hub and the final customers. Tricycles are able to access narrow streets, are not exposed to the problem of limited parking space and decrease the amount of emissions produced through delivery operations inside city centers. However, since not all parcels fit the cargo space of a tricycle, trucks are allowed to visit final customers if these customers require a quantity exceeding the capacity of a tricycle.

All parcels are present at the depot in the morning, when the trucks can pick-up a certain amount of goods and deliver them to the final customers and the city hub. Being located in the inner-city area, the storage capacity of the city hub is limited, which implies that not all goods can be transported from the depot to the city hub at once. Instead, the trucks are obliged to transfer parcels on the first echelon performing multiple trips, while

respecting the capacity of the city hub and the final customer time windows. On the second echelon, tricycles can only start their delivery tours as soon as the goods have arrived to the city hub, thus freeing city hub capacity as parcels are picked-up on multiple trips. We specify time windows (TWs) to indicate the earliest and latest time a final customer demands to receive an order (this trend has become very popular in restaurants or small stores, where the availability of goods at a specific time is crucial for their operation). Nonetheless, TWs can also be used to regulate the access to certain areas at specific times due to public regulations.

Organizing the described distribution scheme is a challenging task, since the coordination of first- and second-echelon trips is necessary: all second-echelon trips depend on the delivery of goods on the first echelon, which is limited by the city hub capacity. We call the problem of optimizing vehicle routes in this distribution scheme the Capacitated Two-Echelon Vehicle Routing Problem with Time Windows (C2E-VRPTW).

The goal of the C2E-VRPTW is to properly determine a set of vehicle routes to satisfy customer demands at a minimum travel cost, while respecting capacity and time constraints.

2 Solution Method

To cope with the challenges encountered in this real-world problem, we propose an iterative three phase solution method aiming at efficiently eliminating infeasible solutions.

2.1 First phase: solving the second-echelon problem

The second-echelon problem corresponds to the final leg of distribution performed by (electric) tricycles. In our characterization, the tricycles cannot start their trips before the goods of the customers to be served by those trips arrive to the city hub. However, for this phase (at least for the first iteration) we assume that all the goods are permanently available in the city hub; meaning that the tricycles can start their trips without waiting for the goods to arrive. Hence, the problem is seen as a Multi Trip Vehicle Routing Problem with Time Windows (MTVRPTW). The first echelon of the problem is not yet considered.

To solve this subproblem, the population-based algorithm developed by Cattaruzza *et al.* [1] for the MTVRPTW with release dates is used. The method proposed in Cattaruzza *et al.* [1] is a population-based algorithm using the giant tour decomposition scheme introduced by Prins [2], coupled with local search operators.

Each solution indicates a set of trips plus the order and assignment of every trip to the tricycles, in such a way that the demand of every customer is satisfied during the imposed TW. The starting time, load, and sequence of nodes to be visited, is given by the

solution for each one of the trips. Moreover, considering that this might not be the final arrangement of the second-echelon trips, load and time window violations are permitted but signalized in the solution.

2.2 Second phase: define the visits to the city hub

After having an initial solution for the second-echelon problem, the next step is to generate an input for the first echelon, based on the information obtained from the previous phase. To accomplish this, a set of visits to the city hub is introduced. These visits are meant to indicate the services that the first-echelon vehicles will need to do to the city hub with the goods for the second-echelon customers, throughout one working day.

The input for this process is the starting time, load, and sequence of the second-echelon trips, together with the city hub capacity. A visit is defined for every second-echelon trip and the demand of the visit corresponds to the load of the related trip. A greedy algorithm is used to determine the visiting time windows for the city hub, respecting its limited capacity.

2.3 Third phase: solve the first-echelon problem

Taking advantage of the fact that the visits defined in the previous phase share the same characteristics as the first-echelon customers, a set of vertices that indifferently refers to the first-echelon customers given by the problem, and the visits defined during the second phase, is fixed.

Through this characterization, the first-echelon problem can further be reduced to an instance of the MTRPTW, by fixing release dates to 0 for all the vertices. Thus, it is solved resembling the first phase of the method, using the algorithm proposed by Cattaruzza *et al.*[1].

In this case, the input for the algorithm will consist in the set of vertices (visits plus first-echelon customers) to be served by trucks in the first echelon with their related demands, time windows, and release dates.

2.4 Iterative Process

From the input defined in the third phase, the algorithm will provide a first-echelon solution. Yet, it might be impossible for the trucks to perform the visits within the established TWs, meaning that the goods of the trip related to that *infeasible* visit will arrive after the stipulated starting time. With this in mind, a new starting time sT^* given by the actual arrival of the goods to the city hub is introduced. This sT^* implies a delay in the service of the second-echelon customers related to that trip. Thus, we also introduce an actual service time aT to refer to this new service time.

After delaying the second-echelon trips, the aT obtained for every customer, may (or may not) violate the TW of the customer. By saying this we imply that even if a trip is delayed, it might still serve some customers in their respective TW; or it can indeed violate their TW. Thus, we make a distinction between these 2 types of customers: customers with an aT that is still within their associated TW, and customers with a TW violation given by the delay of the trip. From this distinction we proceed to update release dates of the second-echelon customers in the first phase, giving way to the iterative process.

3 Results and Conclusion

For testing the performance of our algorithm we use two types of test instances. As a first set of data we use adapted Solomon instances for the VRPTW, while the second set of data is based on real-world information from a parcel delivery company operating in the city of Vienna.

We will present experiments on sensitivity analysis with respect to relevant parameters. First, we vary the capacity of the city hub ranging between half and twice the capacity of the first-echelon vehicles. Second, we investigate the effects of variations in the distance between the depot and the city hub. Results include the CPU time in seconds, the number of used vehicles, the number of first- and second-echelon routes and distance traveled, and the number of iterations of the method.

These parameters act as key performance indicators for decision makers aiming at implementing an efficient two-echelon distribution system with limited storage capacity.

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