Long-haul Parcel Transportation on a Hierarchical Network

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1 Introduction

E-commerce has experienced strong growth over the past two decades. This trend has been further reinforced by the recent pandemic, pushing people to shop even more online. Designing good logistics and transportation networks to handle point-to-point parcel delivery is key to the success of e-commerce. In this work, we focus mainly on the optimization of long-haul parcel transportation on a road network. We consider a two-level hierarchical transportation network containing three types of sites, where parcels pass through and/or are sorted. We want to determine how to exploit such hierarchical structure when designing an algorithm for long-haul parcel transportation. On the one hand, the simplicity of the network structure is useful because it allows to reduce the number of operational paths in the network. On the other hand, introducing this structure would possibly limit some paths resulting suboptimal routings. Thus, our research goal is to understand and find a good trade-off between the simplicity of hierarchical network design and the optimality of the solutions produced by our algorithms.

2 Definition of the long-haul parcel transportation problem

We study the problem of delivering parcels via trucks with twin trailers in a national postal network with around 2000 demands per day between sites on the network. We have two types of sites : each site in our network is either a delivery depot or a sorting center (but cannot be both). We have around 15 sorting centers and 150 delivery depots. Among the sorting centers, some are also inner-hubs (intermediate sites between sorting centers) as determined by the transport managers. So the parcels are to be routed on a road network essentially composed of two hierarchically nested hybrid hub-and-spoke networks. The inner layer consists of sorting centers, some of which are designated as inner-hubs. In the outer network, each sorting center serves as an outer-hub for the corresponding delivery depots that are assigned to this sorting center. For both networks, it is possible to bypass the inner- or outer-hubs, which is why the networks are considered to be hybrid [3].

Parcels are physical objects which must be routed from a specified origin sorting center to a designated delivery depot. We assume all the parcels have the same size which is an average size. The parcels which have the same origin and destination are grouped in a demand. Demands are represented by the triple (origin, destination, number of parcels). At a sorting center, all parcels in a container can be sorted. By sorting, we mean assigning parcels to containers and assigning containers to trucks. This operation has a cost. Between the origin and the destination sites, a parcel can be reassigned (container and/or truck) at at most two intermediate sites. All pairs of sites are connected and there is a cost for routing a truck between two sites. Our objective is to find paths for trucks in the network provided so that each parcel is delivered while minimizing

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the total transportation and sorting costs and respecting the aforementioned reassignment constraints. Moreover, we have to balance the trucks, which means that the number of outgoing and incoming trucks must be equal for each site in the course of a day. Note that as a container can carry parcels with different origins and destinations, an optimal solution might not route a parcel on its shortest path. When a set of demands going to different final sites are put in the same container, it is called consolidation. It allows cost savings as it permits a more parsimonious utilization of trucks, but it makes the problem more computationally difficult.

Hybrid hub-and-spoke networks have been used previously to simplify such networks and reduce the solution space. For example, Zäpfel and Wasner [3] study the planning and optimization of hybrid hub-and-spoke transportation on the case of parcel delivery in Austria, and they demonstrate that a hybrid hub-and-spoke network (with the addition of direct paths between origin and destination points) is optimal in their case. Baumung and Gündüz [1] also used this type of network to consolidate residual volumes on the case of parcel delivery in Germany. In our case study, the number of potential paths is too large to be addressed directly by an MILP, so we need to reduce the size of the problem. In a previous work [2], we tested clustering methods to address this issue. Here, we use the hierarchical structure of the network and the aggregation of demands to reduce the problem size and simplify the solution space.

3 Algorithm for parcel routing via aggregate demands

As the number of possible sorting operations for each parcel is bounded, we set up a path-based MILP. However, this MILP does not yield optimal solutions for a complete data instance in a reasonable amount of time. But it can give optimal solutions for smaller instances (less than 40 sites) in less than 10 minutes. This leads us to consider dividing the original problem into tractable subproblems, guided by the hierarchical nature of the network.

The main idea of this algorithm is to first optimize the transportation on the inner level of the network (sorting centers to sorting centers), then to optimize the extension of this transport plan to the outer level of the network (sorting centers to depots), and finally to optimize on a global level the whole transport plan. Since the original demands of our problem are from sorting centers to delivery depots, we first create aggregate demands which are demands from sorting centers to sorting centers, in order to create a tractable problem for the first level of the network. An aggregate demand is the sum of demands from a sorting center to all the corresponding delivery depots of a same destination sorting center (which is their outer-hub).

If we simply aggregate all the demands into demands from a sorting center to another sorting center and force all parcels to be sorted in their corresponding outer-hub, we will not use any direct paths from a sorting center to a depot. Thus, we split the demands into two sets : the large demands (above a given threshold) which will be separated and allowed to go on a direct path with lower costs, and the residual demands which will be sorted in their sorting center (and maybe also at an inner-hub). This approach gives a solution for the complete instance in reasonable time but it is globally suboptimal because it can remove some possible operational paths that would be chosen in a global optimal solution. We will present experimental results obtained on datasets provided by a postal company and a comparative analysis will be done with those obtained with a global MILP to show the effectiveness of our algorithm with aggregate demands.

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