Model of the Swiss Freight Railway Network Design Problem

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1 Introduction

In a freight railway network, a commodity is usually transferred from the origin station to a hub, where commodities from several origin stations are sorted and grouped by the common destination hub. At the destination hub, grouped commodities are separated again and sent to their final destinations. The purpose of transporting commodities via hubs is to reduce the transport costs, while respecting the limited track capacities. Consequently, the number and locations of the hubs impact these costs to a great extent.

The hubs in railway networks are called marshaling and shunting yards, while the operations of sorting and regrouping the freight is commonly known as freight shunting. The main differences between marshaling and shunting yards are the used technology and the available capacity, i.e. the number of wagons that can be shunted over a certain period of time. In our case, we focus on the latter.

The goal of our work is to determine the optimal number and locations of marshaling and shunting yards in a railway network in order to reduce freight transport and shunting costs. For this purpose, we have defined an optimization problem whose solution determines which facilities should be marshaling or shunting yards and the required capacities of these yards.

The defined problem is intended to be solved and tested over the freight railway network operated by the Swiss transportation company SBB Cargo. Since the SBB Cargo network is too large for the presented optimization problem to be solved with an exact method, we have to rely on heuristics here. However, we intend to solve the problem exactly on a part of the mentioned network and to use the solution as a benchmark to evaluate the correctness and performance of the heuristic algorithm proposed in [5].

The defined problem is presented in more details in Section 2. In Section 3, we present a comparison between our model and the related models found in the literature. The preliminary results of the developed heuristic algorithm are reported in Section 4.

2 Optimization Problem

We have defined our problem as a mixed integer programming (MIP) problem whose solution determines the locations and required capacities of the marshaling and shunting yards with respect to the given transport demand.

The potential locations of shunting or marshaling yards are the existing stations. Each station is represented with an incoming and an outgoing node. Between each pair of station nodes, we model three inner arcs that represent a regular station, shunting yard and marshaling yard. These arcs have zero costs and their maximum capacities depend on the station type. A constraint guarantees that only one of these three arcs can be active at any given station, determining its type.

The model also contains the set of arcs that represent the direct links between the different stations. We also include the set of commodities that need to be transported. Each commodity is defined by the origin and destination stations, number of wagons and weight.

The objective function represents the sum of:

1. transport costs for each commodity assigned to each arc, which are dependent on the commodity weight and arc length,
2. locomotive and personnel costs of each commodity, dependent on the existence of marshaling or shunting yards on the selected route, and
3. costs of freight shunting, dependent on the number of wagons.

If the selected route of a commodity includes marshaling or shunting yards, the commodity is grouped with other commodities into a single train, and its locomotive and personnel costs are thereby multiplied by the fraction of the train length that is taken by it. In the opposite case, the commodity is transported as a separate train and the whole locomotive and personnel costs for this commodity are added to the objective function.

In addition to the standard constraints appearing in hub location problems (HLP, [2]) and multicommodity network design problems (MNDP, [4]), we have included in our model the constraints for:

- modeling that each node can be either a regular station, shunting yard or marshaling yard, and limiting the node capacity according to its type,

- forcing that in each node, all commodities are processed either via the regular, shunting or marshaling inner arc, and
- limiting the number of shunting and marshaling yards in the railway network.

The solution of the problem is the flow on each arc. Each used inner arc and the flow on it determine the type and required capacity of the corresponding station, respectively.

3 Related problems and modeling differences

The defined problem shares similarities with HLPs and MNDPs. Unlike the mentioned problems, in our model the capacity constraints are defined on the nodes and not on the arcs, and the objective function takes into account the hub operating, i.e. freight shunting, costs rather than the hub opening costs. Additionally, its solution simultaneously determines the hub locations and hub types, in terms of the maximum allowed capacity, and solves the contained multicommodity flow problem (MFP). On the other hand, in the available literature, we have not found any other HLP or MNDP that has all mentioned properties combined. In the remaining of this section, we present several selected HLPs and MNDPs and their differences and similarities to the problem presented in this abstract.

In [6], Racunica and Wynter have presented a model used for design of a dedicated or semi-dedicated freight rail network. Their model accounts for the cost of building hubs and assumes that all freight is transported via hub nodes. On the other hand, our model focuses on the hub operating costs instead of the building costs, since the latter represents the investment costs which will be compensated by the savings in the transport. Also, our model gives advantage to the interhub transport by reducing the transport price of the commodities which have gone through the marshaling or shunting yards and have been organized into longer trains. However, it does not impose that a commodity must be routed through a marshaling or shunting yard.

In [2], the authors give a survey of models for several variations of the HLP. Our model shares certain aspects with some of them, but not entirely with any. The most similar to our model is the p-HLP model with limited capacities, which accounts for hub capacities, but does not consider hub operating costs. Also, the mentioned model assumes that all freight must be transported via two hubs which is not imposed by our model.

In [1], the authors have presented a HLP which accounts for both the costs of and time required for the transport, hub operation and hub opening. However, due to the computational complexity of the presented model, the authors have included neither hub nor arc capacities, whereas the former are the key point of our model.

In [4] and [3], the authors give very similar definitions of the multicommodity capacitated network design problem. However, both given models are different from ours in two ways. Firstly, they account for the cost of opening hubs, while the objective function of our model includes the cost of hub operation. Secondly, the presented models do not contain different arc types, each corresponding to a different discrete capacity level. On the other hand, our model determines the type of each node, with the corresponding capacity.

4 Preliminary results

With the presented model and developed heuristic algorithm [5], we expect to design a network with lower freight transport and yard operation costs in comparison to the current network. The preliminary results suggest that the mentioned costs can be decreased around 5% by reducing the number of marshaling and shunting yards as well as relocating some of them. By the time of the conference, we expect to have the results of the heuristic algorithm, confirmed by the exact solution of the presented problem on a part of the real network. Also, the algorithm has proven our expectations regarding the performance. It reaches a solution in approximately 20 minutes which is a reasonable amount of time considering the size of input data.

References

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