Network design for freight transportation in a river network

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1 Introduction

The use of rivers as transport corridors offers a cost-effective and environmentally sustainable alternative to road transport, facilitating the seamless movement of cargo from major maritime hubs to hinterland port cities.

The objective of this research is to design an efficient transport service, inspired by the principles of the Physical Internet (PI), in a network that includes seaports and a set of river ports. This specific network is a missing link between local/regional road networks and deep sea transportation lines. The river ports include two types of facilities : PI hubs (transshipment ports), where transshipment operations can be performed, and other ports, where the cargo can be loaded or unloaded, but not transshipped.

In this context, we present a mixed-integer linear programming model for a service network design problem that aims to make the following decisions : (i) define the regular routes that operate in the river network, (ii) assign a fleet of vessels to each route and determine their frequency, and (iii) route a set of transportation demands (called commodities), with the possibility of multiple transshipments between their origin and destination.

2 An overview of the mathematical formulation

We consider a network similar to the one shown in Figure 1, including a set of sea ports, a set of PI-hubs located on rivers, and a set of river ports where no transshipment operations can be performed.

Our route-based considers a set of candidate routes, which can be of several types : circular, butterfly, pendulum, etc. [1]. A route is a sequence of port calls.

We consider a set K of commodities. Each commodity $k \in K$ is characterized by the triplet (o_k, d_k, q_k), where o_k is the origin port, d_k is the destination port and q_k the quantity to be moved from o_k to d_k. Commodities cannot be split.

Following [2], we consider several classes of ships that can sail along the river network : river-sea ships can call at both river ports and sea ports, while several sizes of river ships are defined depending on the part of the river they navigate. Each type of vessel has a given capacity and associated costs.

We propose a mathematical model that selects a subset of routes and ships that will achieve transportation of all goods at minimum cost. The sets of constraints model flow conservation, demand satisfaction, and vessel capacity constraints. In addition, a number of constraints

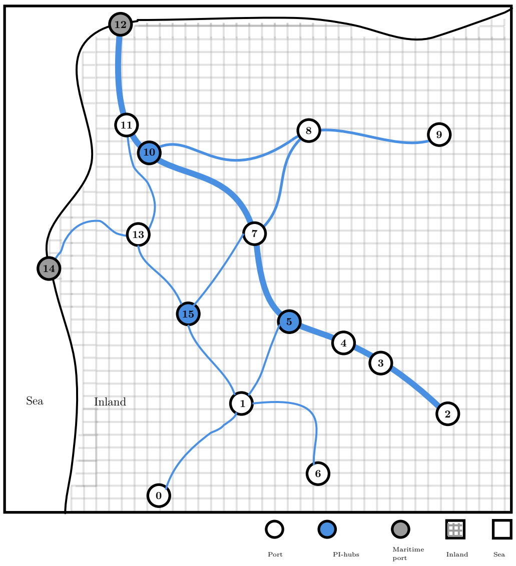

FIG. 1 – River-sea network

relate to loading, unloading, and transshipment operations. For example, a commodity cannot be unloaded before it is loaded, it cannot be transshipped on the same route, etc.

3 Case study and managerial insights

The mathematical model is tested on several case studies based on real river networks (Rhine, Danube, Mississippi and Magdalena river). The routes and the commodities were manually generated according to the traffic observed on Vesselfinder.com. For example, the case study in the Rhine/Meuse/Main inland waterway axis includes the ports of Antwerp and Rotterdam, as well as a list of 3 PI-hubs and 11 river ports in the Netherlands, Germany and Belgium. The mathematical model is solved with Gurobi 10.0.1 (linux64), on a a computer with a 3.00 GHz processor, and using up to 8 threads. Instances with up to 80 commodities can be solved to optimality with a time budget of two hours.

We present the results of numerical experiments, where we assess a number of additional business constraints and constraint related to PI networks : (i) we consider an upper bound on the number of transportation lines. (ii) following the idea of relay network design (see, e.g., [3]), we assume that the set of selected routes forms a partition of the network's edges, thus prohibiting overlapping lines. (iii) we introduce capacity constraints at PI-hubs.

Références

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