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Hub location problems in transportation networks

Shahin Gelareh [a,d,*], Stefan Nickel [b,c]

[a] Department of Management Engineering, Technical University of Denmark, Produktionstorvet, Building 426, 2800 Kgs. Lyngby, Denmark
[b] Institut für Operations Research, Universität Karlsruhe, D-76128 Karlsruhe, Germany
[c] Department of Optimization, Fraunhofer Institute for Industrial Mathematics (ITWM), D 67663 Kaiserslautern, Germany
[d] LAGIS FRE CNRS 3303, Ecole Polytechnique de Lille, Avenue Paul Langevin, 59655 Villeneuve d'Ascq, France

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ABSTRACT

In this paper we propose a 4-index formulation for the uncapacitated multiple allocation hub location problem tailored for urban transport and liner shipping network design. This formulation is very tight and most of the tractable instances for MIP solvers are optimally solvable at the root node. While the existing state-of-the-art MIP solvers fail to solve even small size instances of problem, our accelerated and efficient primal (Benders) decomposition solves larger ones. In addition, a very efficient greedy heuristic, proven to be capable of obtaining high quality solutions, is proposed. We also introduce fixed cost values for Australian Post (AP) dataset.

1. Introduction

In the last two decades, due to an enormous increase in the body of telecommunications, transportation and logistics, several different cooperative strategies such as alliances and coalitions are either formed or investigated and many industrial studies are devoted to these areas. In such studies, hub-and-spoke structures have received a lot of attention as they offer possibilities of efficient capacity sharing and fleet management on different legs of transport routes. This leads to a better utilization of transporters such as vehicles and vessels. While public transport networks and liner shipping industries evidently operate on hub-and-spoke network structures, Hub Location Problems (HLP) have not received significant attention in these areas in the literature.

Aiming at minimizing the total costs, maximizing utilization of transporters, maximizing the service level, etc., in a hub-and-spoke network, the flow between O–D pairs is routed through some selected intermediate nodes (called *hub* nodes) and edges (called *hub edges*) connecting the hubs. Once the hubs are chosen, the non-hub nodes (called *spoke* nodes) are allocated to them in order to transship flow via the sub-graph composed of all the hub nodes and the hub links connecting them (called *hub-level (sub-)network*). The allocation scheme is either single or multiple based on the particular nature of application. In a single allocation scheme, a spoke node is allocated to a single hub, while such restriction is relaxed in a multiple allocation scheme. Such a hub-and-spoke structure avoids direct shipping, which results in underutilized (or at least very infrequently utilized) use of vehicles/vessels operating on some (or perhaps many) of the direct links and drops the

* Corresponding author at: Department of Management Engineering, Technical University of Denmark, Produktionstorvet, Building 426, 2800 Kgs. Lyngby, Denmark. Tel.: +45 4525 3386.
E-mail addresses: shge@man.dtu.dk, shahin.gelareh@gmail.com (S. Gelareh).

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underutilized links in favor of concentrating flow on hub edges and better utilization of facilities operating there. As a result of this flow concentration, economies of scale can be exploited by using more efficient transporters on the hub links.

In classical HLP models, four main assumptions are usually considered (Nickel et al., 2001):

(i) The hub-level network is a complete graph.
(ii) Using inter-hub connections has a lower price per unit than using spoke connections. That is, it benefits from a discount factor α,($0 < \alpha < 1$).
(iii) The direct connections between the spoke nodes are not allowed.
(iv) The triangle inequality holds in the cost structure and costs are proportional to the distance.

In applications like public transport and in particular liner shipping which are the main areas our model addresses, the structure of hub-level sub-network plays a major role in the level of service offered to the users and also vital for the sustainability of business in such highly competitive environments.

1.1. Urban transport

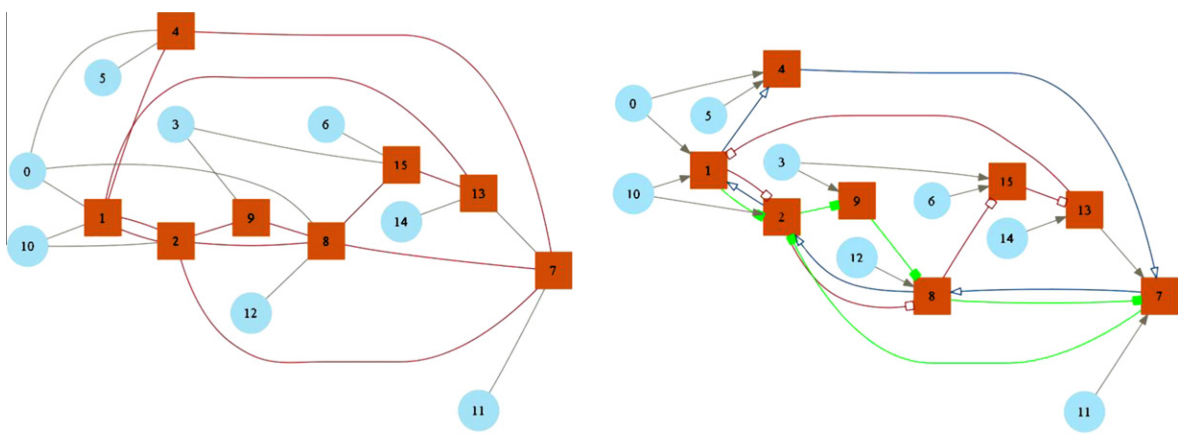
Most of hub-and-spoke network structures proposed in the literature are based on a point-to-point connection between hub nodes (complete hub-level sub-graph), and are very rarely applicable to real-life cases. In a city with at least two choices of service (e.g. bus, metro, subway and train, etc.), the hub nodes are usually chosen from among the nodes where bus lines intersect or pass by a reasonable proximity of other fast-lane services. The fast-lane tracks are considered to be the hub edges while the bus lines are assumed to be spoke edges. Given that such nodes are potential hub nodes, direct point-to-point connections between all the fast-lane stops is rarely available (the fast-lane sub-network is not usually a complete graph). Moreover, due to a priori existence of infrastructures (or even historical architecture, environmental barriers, parks, etc.) it may not be possible to have complete hub-level sub-graphs (even if economically advantageous).

A typical hub-and-spoke structure in public transport is depicted in Fig. 1. In this figure the rectangles are hub nodes and the circles are spoke nodes. The allocation follows the multiple assignment scheme and the hub-level is not complete. Once a passenger/commodity departs from origin and arrives at the first hub node, the number of hub level links which must be traversed before arriving at the destination is not restricted to at most two (as the case in the classical HLP models).

Three different operating fast-lane tracks of the plain hub-and-spoke structure in Fig. 1a distinguishable by different rectangular arrow-heads are depicted in Fig. 1b. We must also note that, there might exist spoke connections between two hub nodes which coincide with the existence of bus lines between two fast-lane stops, if advantageous. This is depicted in the figures by the spoke line between nodes 7 and 13.

1.2. Liner shipping

Up to 90 percent of global trade volume is transported as containerized cargo on vessels where again up to 90 percent of such vessels are fully cellular container vessels (UNCTAD, 2008). The network structure is based on hub-and-spoke models. As shown in Fig. 2a in an east-bound voyage (in this case, the *Asia–Europe (AE7)-East Bound*) a vessel starts from European Container Terminal (ECT) in Rotterdam while feeder vessels (spoke-link-operating vessels) have supplied it with containers from different smaller ports destined to east Asia. The vessel later calls Felixstowe in UK where it delivers all containers that



(a) Plain hub-and-spoke structure. (b) Transportation hub-and-spoke structure.

Fig. 1. A typical hub-and-spoke structure.