Transportation Research Part E 48 (2012) 1107–1120

Contents lists available at SciVerse ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

Hierarchical multimodal hub location problem with time-definite deliveries

Sibel A. Alumur [a,*], Hande Yaman [b], Bahar Y. Kara [b]

[a] Department of Industrial Engineering, TOBB University of Economics and Technology, Söğütözü 06560, Ankara, Turkey
[b] Department of Industrial Engineering, Bilkent University, Bilkent 06800, Ankara, Turkey

ARTICLE INFO

Article history:
Received 16 September 2011
Received in revised form 2 April 2012
Accepted 3 April 2012

Keywords:
Hub location
Time-definite delivery
Multimode transportation
Hierarchical network design
Valid inequalities

ABSTRACT

Hierarchical multimodal hub location problem is a cost-minimizing hub covering problem where two types of hubs and hub links, accounting for ground and air transportation, are to be established, while ensuring time-definite deliveries. We propose a mixed-integer programming formulation and perform a comprehensive sensitivity analysis on the Turkish network. We show that the locations of airport hubs are less sensitive to the cost parameters compared to the locations of ground hubs and it is possible to improve the service quality at not much additional cost in the resulting multimodal networks. Our methodology provides the means for a detailed trade-off analysis.

1. Introduction

Hub facilities are present in various many-to-many distribution networks such as airline, cargo delivery, and telecommunications networks. In all of these networks, traffic between the demand nodes is routed via the hub facilities. Even though the basic structure of the traffic movement is the same, each application area has its additional requirements and specifications.

In this paper, we focus on the operational characteristics of cargo delivery networks. In a typical cargo delivery network, goods that need to be delivered are first collected at branch offices. The cargo processing operations, such as sorting, are carried out at hub facilities. These hub facilities are consolidation and dissemination centers. In hubs, cargo from different origins but similar destinations is collected together and re-routed according to their destinations. A package arriving at a hub can travel directly to its destination, if the destination branch office has a connection with this hub, or travels to the hub to which the destination is allocated. Due to managerial reasons, usually each branch office has connections with only one hub; that is, the in- and out-going traffic of each branch office is processed at a single hub.

Due to the competitive environment in the market, companies pay more attention to service levels. In cargo delivery, service level is primarily measured via delivery time, which is the time the parcel arrives at its destination. Cargo companies offer different delivery time promises, such as next day or second day delivery, to their customers.

‘Next day delivery’ or ‘delivery within 24 h’ is the current target for the cargo companies operating in Turkey. However, due to geographical distribution of the cities within Turkey and the structure of the highways, delivery within 24 h between all city pairs is not possible if only ground transportation is employed. Mainly due to the competitiveness in the sector, recently the cargo companies in Turkey investigate the costs and benefits of including airlines into their distribution networks. In particular,

* Corresponding author. Tel.: +90 312 2924136; fax: +90 312 2924091.
E-mail addresses: salumur@etu.edu.tr (S.A. Alumur), hyaman@bilkent.edu.tr (H. Yaman), bkara@bilkent.edu.tr (B.Y. Kara).

1366-5545/$ - see front matter
http://dx.doi.org/10.1016/j.tre.2012.04.001

one of the cargo companies utilizes airline segments in its hub network and promises deliveries within 24 h between every origin–destination pair of Turkey. The company uses a star-shaped airline network that is rooted at the capital city Ankara.

Motivated by the operating characteristics of this company's service network, in this paper, we introduce a new hub location problem. In the sequel, we explain the operating structure of this type of service network in detail.

In this network, there are two different types of hubs: ground hubs and airport hubs. Each demand node is connected to a single hub via a highway segment. Additionally, each ground hub is connected to an airport hub via a highway segment, and each airport hub is connected to the central airport hub via an airline segment. Thus, the airline network has a star structure centered at the central airport hub. If two ground hubs are allocated to the same airport hub, then a direct highway segment can be established between these ground hubs. Even though the motivating example enforces a highway connection between any two ground hubs served by the same airport hub, we relax this assumption in our models and computational study, but, as extension we also discuss how to model this requirement.

Fig. 1 depicts a service network with eleven hub nodes (nodes 0, ..., 10). In this figure, airport hubs are illustrated as triangles (nodes 1, 2, 3), ground hubs as squares (nodes 4, ..., 10), and the central airport hub is illustrated as a circle (node 0). Remaining unnumbered nodes are the demand nodes that are allocated to these hub nodes. Double lines represent airline connections, whereas single lines represent truck connections. Observe from Fig. 1 that the hub network has two levels: the first level is the star-shaped airline network and the second level is the union of mesh networks established for each airport hub.

In our hierarchical network, if two hubs are allocated to the same airport hub and if there is a direct highway segment in between, then the flow between these two hubs travels on this direct highway segment. If a direct highway segment is not established between two hubs that are allocated to the same airport hub, then the flow is routed using the highway segments allocating these hubs to their hub airport. On the other hand, if two hubs are allocated to two different airport hubs, then the traffic between them uses the highway segments connecting the hubs to their airport hubs and the airline segments connecting the associated airport hubs to the central airport hub. In the network depicted in Fig. 1, the flow between hub nodes 4 and 5 travels directly by using the highway segment in between, the flow from hub node 4 to hub node 6 follows the path $4 \rightarrow 1 \rightarrow 6$, whereas the traffic from hub node 4 to hub node 7 follows the path $4 \rightarrow 1 \rightarrow 0 \rightarrow 2 \rightarrow 7$. Note that, as pointed out by Smilowitz and Daganzo (2007), unlike airline passengers, cargo can be routed through more hubs if this results in economies of scale and cost savings.

In our application, both directions of a highway or airline segment incident to the central airport hub are served by the same vehicle. For instance, the airplane that travels from airport hub 1 to the central airport hub waits for the vehicles that arrive here from other nodes and then travels back to airport hub 1.

In this paper, we study the design of this type of a hierarchical multimodal hub network. We are given a set of demand nodes, a set of possible locations for ground hubs, a set of possible locations for airport hubs, the location of the central airport hub, the number of hubs to be opened, and the required cost and time parameters. The aim is to find the locations of the ground and airport hubs, the allocations of demand nodes to these hubs, the allocations of ground hubs to airport hubs and to route the flow to minimize the total transportation and operational costs while ensuring that each pair of demand nodes receive service within a predetermined time bound. We refer to this problem as the *hierarchical multimodal hub location problem with time-definite deliveries (HMHL-TDD)*.

The hub location problem is first posed by O'Kelly (1986, 1987). Given a set of origin–destination pairs with positive flow, the hub location problem involves the decisions on the locations of the hubs and the allocations of the demand nodes to these hubs. O'Kelly (1987) proposes a cost minimizing formulation of the problem, which may be considered as the first model in the hub location literature.

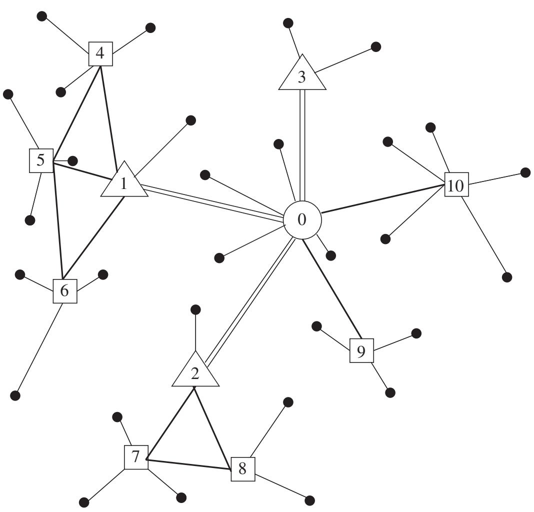

Fig. 1. A hierarchical multimodal hub network with eleven hub nodes.