Transportation Research Part E 114 (2018) 104–120

Contents lists available at ScienceDirect

Transportation Research Part E

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

Hub network design problem with profit optimization for time-definite LTL freight transportation

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ARTICLE INFO

Keywords:
Hub network design
Hub median problem
Pricing
Hub-and-spoke network

ABSTRACT

Time-definite less-than-truckload (LTL) carriers deliver small, time-guaranteed shipments for shippers. We analyze the hub network configuration under cost minimization and profit maximization behaviors. We extend a perfect inelasticity on demand with cost minimization to an elastic demand hub location design with profit maximization. We formulate this problem as a mixed-integer program that is solved using implicit enumeration with an embedded pricing subproblem. The computational results for a carrier's operational network in Taiwan showed that different behaviors result in noticeably different pricing and demand distributions. In addition, profit optimization builds a denser hub network than cost minimization to increase profit.

1. Introduction

Network industries include ground (Lin, 2001) and air (Lin and Chen, 2008) parcel delivery, postal services (Grunert and Sebastian, 2000; Ebery et al., 2000), airlines (O'Kelly, 1987; Jaillet et al., 1996) and telecommunications (Klincewicz, 1998; Yoon et al., 1998). Providers of network industries are *carriers* that provide point-to-point services to shippers. *Centers* (non-hubs) pick up/deliver shipments from/to shippers/consignees. Shipments are unloaded, consolidated and reloaded at *hubs*, which are the points of consolidation. Centers and hubs collectively form a hub-and-spoke (H/S) network. This type of network configuration with no direct center-to-center movements is known as a *pure* H/S network (*P*-H/S), as shown in Fig. 1; this configuration reduces partial center-to-center direct loads. The reduction in transportation costs outweighs the increase in the hub re-handling *variable* costs, resulting in an overall decrease in operating costs. In addition, the net decrease in the variable operating cost is outweighed by the increase in *fixed* hub investments. For these reasons, *P*-H/S is the most common operational network for carriers (Lin and Chen, 2008).

With cost minimization, the carriers' hub network design problem in a *P*-H/S network is to determine the strategic locations of hubs and operational paths for origin-to-destination (OD) pairs to minimize the sum of the fixed hub cost and the operating cost while complying with the relevant operational restrictions. This problem consists of two interactive decisions: the *strategic* decision for hub locations and the *operational* decision for *constrained* freight paths. A *path* is a sequence of facilities that originates at the *origin* center and terminates at the *destination* center via a single hub or multiple hubs for consolidation. In some applications, hubs may operate multiple *sorts* per day. As a result, the freight path is labeled with the precise *sorts* of their respective hubs (Lin, 2001). Designing a cost-efficient hub network that can execute the most cost-effective operation is one of the core competencies for network industries.

However, let us observe the following example. Suppose that the market demand function is $p = 317.03q^{-0.372}$ (Lin et al., 2009). A carrier exists whose *P*-H/S network consists of 2 hubs, A and B, and 4 centers, 1–4, as shown in Fig. 2. The operating cost per unit of distance is \$1, the handling cost per unit at the hub is \$1, and the fixed hub investment cost per hub is \$5000.

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https://doi.org/10.1016/j.tre.2018.03.007
Received 15 June 2017; Received in revised form 22 February 2018; Accepted 16 March 2018

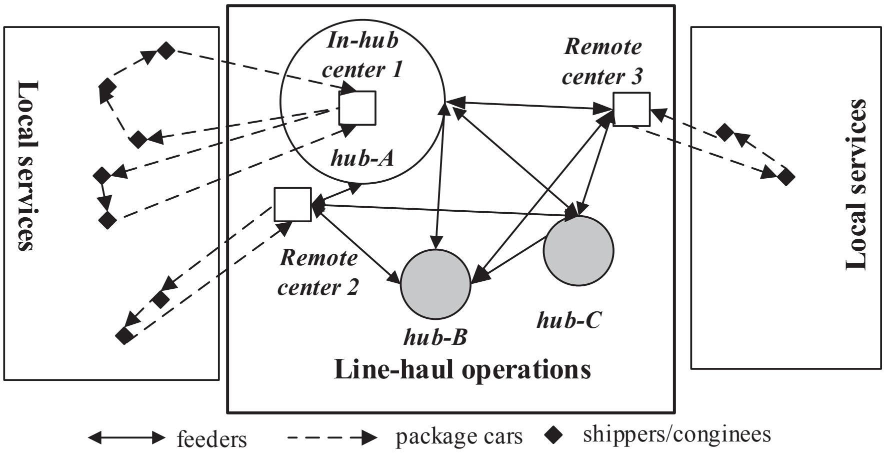

Fig. 1. An illustration of the time-definite LTL operations network.

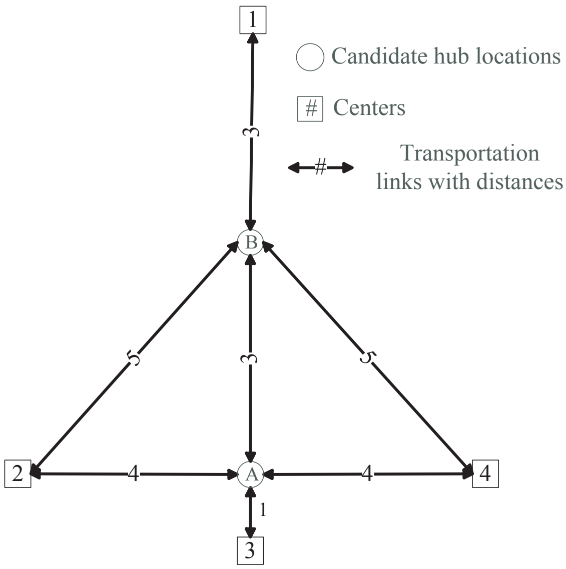

Fig. 2. A 2-hub and 4-center *P*-H/S network.

If the carrier's business goal is to minimize its operating cost, it will construct a single-hub network at location B at a total cost of $154519.56, as shown in Table 1.

With profit-maximization behavior, the carrier will assume that demand is sensitive to price and may integrate *tactical* pricing

Table 1
The operating cost and profit for a single-hub network.

	At location A					At location B				
ODs	Unit cost	Demand	Price	Total variable cost	OD profit	Unit cost	Demand	Price	Total variable cost	OD profit
1-2/2-1	13	1533.90	20.70	19940.72	11812.02	11	2403.40	17.52	26437.40	15660.37
1-3/3-1	11	2403.40	17.52	26437.40	15660.37	13	1533.90	20.70	19940.72	11812.02
1-4/4-1	8	5657.28	12.74	45258.23	26809.01	12	1902.15	19.11	22825.76	13520.99
2-3/3-2	13	1533.90	20.70	19940.72	11812.02	11	2403.40	17.52	26437.40	15660.37
2-4/4-2	10	3105.25	15.92	31052.52	18394.17	10	3105.25	15.92	31052.52	18394.17
3-4/4-3	8	5657.28	12.74	45258.23	26809.01	12	1902.15	19.11	22825.76	13520.99
Sum				187887.82	111296.60				149519.56	88568.91
				Total cost **192887.82**	**Total profit** **106296.60**				**Total cost** **154519.56**	**Total profit** **83568.91**