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A hybrid hub-and-spoke postal logistics network with realistic restrictions: A case study of Korea Post

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ABSTRACT

Postal logistics has a complex transportation network for efficient mail delivery. Therefore, a postal logistics network consists of various functional sites with a hybrid hub-and-spoke structure. More specifically, there are multiple Delivery & Pickup Stations (D&PSs), multiple Mail Processing Centers (MPCs), and one Exchange Center (EC). In this paper, we develop two mathematical models with realistic restrictions for Korea Post for the current postal logistics network by simultaneously considering locations and allocations. We propose an Integer Linear Programming (ILP) model for transportation network organization and vehicle operation and a Mixed Integer Linear Programming (MILP) model that considers potential ECs for decision making while simultaneously regarding the EC location, transportation network organization, and vehicle operation. We use modified real data from Korea Post. Additionally, we consider several scenarios for supporting EC decision makers. The proposed models and scenarios are very useful in decision making for postal logistics network designers and operators.

1. Introduction

In Korea, mail operation machines and indoor transportation facilities, such as conveyors and sorting machines, are supplied to the main post offices to improve the productivity of mail operations. To raise the efficiency of the entire postal operation, Korea Post has promoted mechanization since 1985. However, the construction of mail processing centers (MPCs) is capital-intensive regarding the mechanization and automation of logistics; thus, it is difficult to change the mail logistics scheme. It is necessary to develop a strategy for radically changing logistics processes over and beyond the efficiencies of individual nodes in the logistics network. In this respect, a hub-and- spoke scheme is a major enabler of integration strategies in mail logistics. For radical changes in mail logistics, the scheme was redesigned to comprise one EC (Exchange Center) and 25 MPCs. A hybrid hub-and-spoke system involves a single EC as a hub and transport between the EC and the 25 MPCs as well as between the 25 MPCs. This approach towards mail logistics has shifted mail from rail freight to road freight. Twenty-five MPCs and one EC are currently involved in the automated dispatching and sorting operations through the network of MPCs (Fig. 1).

For hub-and-spoke transportation systems, we must identify both strategic and operational decisions. The strategic decisions for a hub-and-spoke transportation system include the following: the selection of suitable locations for consolidation, the assignment of customers to sending and receiving depots, the determination of line-haul routes, and the choices of the types of transportation facilities. Operational decisions, which are based on strategic decisions, include the disposition of the number of vehicles for line-haul, and the planning of pick-up and delivery tours for parcels or part-loads to the customers from each depot (Zäpfel & Wasner, 2002).

Increased competition in the transportation market has led to new cooperative arrangements between third-party logistics providers in the form of hub-and-spoke systems. In addition to the design problem, operational planning for a hub-and-spoke network is a challenging task for the management of such transportation networks. Specifically, transportation management has to decide whether a pure hub-and-spoke system should be implemented, where all of the quantities within the transportation network flow over the hub to and from the depots, or whether a hybrid hub-and-spoke network is preferred in which direct transportation also takes place.

The network problem occurs in postal logistics is very complex and diverse. Moreover, the amount of data is enormous which makes the decision makers difficult to design the network. In

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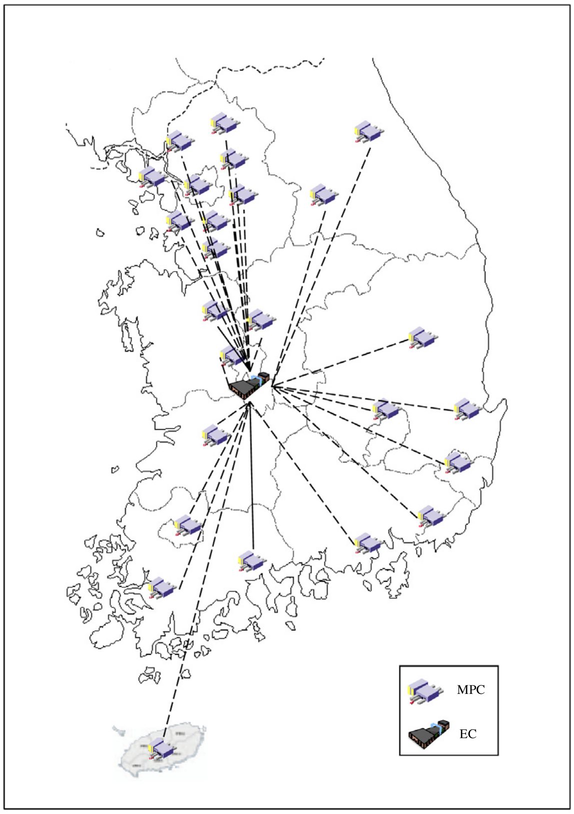

Fig. 1. Current automated facilities in the postal logistics network.

postal logistics, the efficient design and operation of the transportation network is a very important issue. However, it is difficult to flexibly operate the postal logistics network according to changes in the mail volume. In the Korea Post, a transportation plan is pre-determined and the transportation of mail is performed through the routes in the plan. When the routes cannot transport all of the mail, temporary vehicles are used. In postal transportation, it is important to develop a good transportation plan and to efficiently manage the plan. However, it is difficult to change the transportation plan because hundreds of vehicles are involved; thus, planning is required in advance.

Today, Korea Post is actively participating in the nationwide green movement, attempting to transform itself into a more environmentally friendly business by declaring the "2020 Green Post" strategy. They are already prepared for new laws on green growth and for cuts in greenhouse gas emissions, as well as for energy saving policies of government agencies. The postal business has an interest in green logistics, needing to meet the government's requirements. Especially, the delivery vehicle problem is associated with the postal logistics network. Therefore, the results of this paper can be usefully applied to postal logistics.

2. Literature review

The efficient design and operation of transportation networks is a very important issue (Lee, Moon, & Park, 2010). Recently, research has highlighted simulation technology that can model realistic problems and enables quantitative analysis (Ding, Benyoucef, & Xie, 2009; Kim et al., 2003; Wert, Bard, deSilva, & Feo, 1991). However, existing research results are focused on the development of simulations to support decision making from a broad perspective. Therefore, in some circumstances and especially in postal logistics networks, the development of simulations that reflect real situations cannot be accomplished (Cheung & Bal, 1998).

The implementation of hub networks is performed to consolidate flows from different origins and to ship them via hubs to different destinations, thus reducing total transportation costs. In hub networks, all of the hubs are interconnected, and none of the non-hubs are directly connected to each other. Each of the non-hub nodes is allocated to either multiple hubs or a single hub. Many studies have shown that the implementation of hub networks can lower total transportation costs, and successful applications of hub networks have arisen in many areas (Abdinnour-Helm, 2001; Bania, Bauer, & Zlatoper, 1998; De Camargo & Miranda, 2012; Elhedhli & Hu, 2005; Klincewicz, 1998; Kuby & Gray, 1993).

For strategic decision problems concerning hub-and-spoke systems, considerable literature is available. O'Kelly (1986, 1987) was the first to examine the problem of designing hub-and-spoke systems through the formulation of a quadratic programming problem. Because the number of possible sets of hub locations increases exponentially with the size of the problem, the proposed solution method is limited to small-scale transportation networks. Some researchers have decomposed the hub-location problem into two sub-problems (hub location and routing) and applied different solution methods. Skorin-Kapov and Skorin-Kapov (1994) used tabu search to find good solutions for each sub-problem. Aykin (1995) investigated two different variants of the hub design problem. In the first variant, all of the traffic from a given point must flow through a specific hub before proceeding to its destination. The second variant permits trips from a given origin to different hubs depending on the destination. Aykin (1995) developed an enumeration method for multiple allocations and a branch-and-bound method for the single allocation case. Campbell (1996) proposed heuristics that rely on first solving the multiple assignment problems via a greedy exchange method and then using this solution to develop a network of hubs and allocations for the single assignment problem. A more comprehensive review of mathematical modeling for hub design can be found in several studies (Campbell, 1994; O'Kelly & Miller, 1994; O'Kelly et al., 1997).

The general operational decisions in hub-and-spoke systems have received little attention in the literature, although many publications address a related problem. Specifically, the incorporation of direct transportation in pure hub-and-spoke systems was discussed in Lumsden, Dallari, and Ruggeri (1999). These authors provided an overview of hub-and-spoke systems and proposed some possible improvements to this practice for freight transportation.

Lumsden et al. (1999) improved upon the pure hub-and-spoke system. Specifically, they applied the re-allocation of transportation resources and direct connections between pairs of nodes in the distribution network in a case study. All of the aspects of feasibility were discussed, and alternative solutions were compared to the present configuration in terms of the average lead times, the flow of goods, truck utilization rates, and transportation costs. Zäpfel and Wasner (2002) noted that transportation management has to decide whether a pure hub-and-spoke system should be implemented, where all of the quantities within the transportation network flow over the hub from or to the depots, or whether a hybrid hub-and-spoke network is preferred in which direct transportation also takes place. Taha, Taylor, and Taha (1996) presented a simulation-based software system for evaluating hub-and-spoke transportation networks. Park, Lee, Choi, and Lee (2005) developed a simulation model to evaluate the performance of a postal transportation plan in Korea Post. Liu, Li, and Chan (2003) proposed a mixed truck delivery system and a heuristic algorithm with hub-and-spoke and direct shipment delivery. Recently, the hub-and spoke design for the container ship network can be found in several studies (Gelareh, Maculan, Maheye, & Monemi, 2013; Konings, Kreutzberger, & Maraš, 2013).