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Intermodal logistics: The interplay of financial, operational and service issues

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ABSTRACT

This research addresses strategic planning for an interregional, hub based, intermodal logistics network operated by a logistics service provider. A tabu search meta-heuristic is used to solve a mathematical optimization model that extends the p-hub median model for interacting hub location-allocation problems to the domain of intermodal logistics. An empirical study based on a subset of US freight flows shows that intermodal logistics networks differ significantly from traditional over-the-road logistics networks in their hub locations, network structure, and their use of direct and inter-hub shipments. Furthermore, intermodal logistics networks are more sensitive to changes in service requirements and costs.

1. Introduction

The competitive marketplace requires an efficient and effective logistics strategy. Such a strategy aims at managing shipments across geographically dispersed supply and demand areas within a reasonable time and at a competitive cost. To fulfill those needs, intermodal logistics networks offer a viable option (Arnold et al., 2004; Gooley, 1997). In an intermodal network, a shipment uses multiple modes of transportation in its journey from the origin to the destination in a seamless manner through the use of intermodal containers (Crainic et al., 2007; Slack, 1990; Slack, 2001). However, the design and the management of such a logistics network is restricted by the existing transportation infrastructure, location of modal transfer points and logistics cost structure (Warsing et al., 2001).

The growth of intermodal logistics initially resulted from the globalization of the marketplace. This globalization was facilitated by the regional and global trade agreements such as GATT and NAFTA (McCalla, 1999). The use of intermodal shipments has also been on the rise in the US domestic freight market. Even under current lagging economic conditions, domestic intermodal usage has been steadily increasing (IANA, 2008). The sustained demand for intermodal shipments has paid high dividends for logistics companies, such as J.B. Hunt, Schneider National and Swift, which offer domestic intermodal services to their customers (Schwartz, 1992).

Intermodal logistics uses the benefits of its constituent transportation modes to deliver a competitive service compared to the traditional over-the-road (OTR) networks (Macharis and Bontekoning, 2004). The integration of modes within an intermodal logistics network provides the means to move shipments between the origins and the destinations which is both economical and operationally viable (Slack, 1990). The competitiveness of the intermodal networks is not only based on the lower cost, but also on the shipment capabilities. These capabilities are characterized by weight, volume, access and transit time performance. The limitations of the OTR network in terms of shipment weight and volume is overcome by the weight/

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volume capability of rail; limitations in terms of access to rail is overcome by using road for pickup and delivery of an intermodal shipment (i.e., drayage).

Intermodal logistics offer opportunities that go beyond an alternative for truckload (TL) shipments. Intermodal services are designed for less-than-truckload (LTL) shipments as well. Services such as EMP Domestic Container Program offered by the rail carriers Union Pacific and Norfolk Southern provide LTL carriers an opportunity to integrate the intermodal component to their LTL/package handling operations. The prioritization of the intermodal trains on the rail tracks under programs such as the Blue Streak Service of Union Pacific and the Premium Container Service of BNSF Railway offer competitive transit times to many major markets in direct competition to the long haul (more than 500 miles per day) OTR services. The intermodal services are already being used by the package carrier United Parcel Service (UPS). UPS, which started as a package carrier using air transportation, has added road and rail shipments to its operations. Their use of road/rail/air has expanded to an extent that UPS is now the largest US customer of intermodal services.

Over the years, a hub based network structure has evolved for moving intermodal shipments. The emergence of hub based intermodal networks indicates that economy of scale is the principle force behind their use (Slack, 1990). Because an intermodal network is an extension of its respective single mode networks, it is natural that the hub network has emerged as the most suitable network structure for intermodal logistics (Bookbinder and Fox, 1998).

In a hub-and-spoke logistics network, cost savings are realized due to the concentration of flows between the hubs. This concentration of flows creates economies-of-scale and density. Economies-of-scale are realized through the consolidation of less-than-truckload shipments into containerized shipments which reduce the unit transportation cost. The economies of density are realized by high load factors for the road/rail/air shipments over fixed distances. The economies-of-scale create a non-linear rate structure where the unit transportation cost is a non-increasing function of the volume shipped. Intermodal rail and air freight have cost structures which are based on a container-load and are inherently different from the road transportation costs.

This research focuses on the design and management of a hub based logistics network for a logistics service provider that serves a multiregional customer base. Such a service provider manages shipments between origins and destinations through the use of different modes of transportation such as road, intermodal rail, and air. At a strategic planning level, such a logistics service provider must develop general, long-term policies about the location of logistics hubs for shipment handling (consolidation, staging, and break-bulk), the routing policies for shipments, the choice of transportation modes and associated freight flow levels, the planning of resource requirements, and the service design.

The hub network design for such an organization involves identifying the number and location of logistics hubs and the assignment of shipments that are served by each hub. In the context of this research, a logistics hub is a shipment handling facility that receives, consolidates or breaks down, and dispatches shipments. Such a logistics hub may have local access to road, intermodal rail, or air freight terminals that may be operated by other carriers or service providers. The choice of mode (road, rail, or air) for moving a shipment between hubs is determined by the tradeoff between the service requirements quoted to the customer and the transportation cost associated with each mode. The intermodal transfer of shipments is managed through the services offered by the carriers that serve a specific mode. The movement of shipments over-the-road may be done through private assets owned by the logistics service provider as in the case of a firm such as J.B. Hunt or through the use of a third part carrier as in the case of a firm such as Landstar Logistics.

The analysis conducted in this research is focused on the financial, operational and service aspects of intermodal logistics networks. For a large number of companies, the design of the logistics network is based on the road freight. This research seeks to identify the economic benefits gained by using intermodal shipments in a logistics network. Any economic benefit gained by using intermodal shipments may also alter the structure of the optimal logistics network. This research analyzes the changes in the hub locations and service area allocations due to the use of intermodal shipments. The cost of providing intermodal services, i.e., modal connectivity cost, at a logistics hub acts as a tradeoff for any potential economic benefits. The interplay between the modal connectivity cost and the modal choice is analyzed.

The performance of a logistics network can be gauged on different metrics such as cost, service frequency, service time, delivery reliability, flexibility and safety (Beuthe and Bouffioux, 2008). In this research, total network costs and service time are used as the performance criteria (Crainic and Laporte, 1997). More specifically, the model used in this research minimizes total network costs while satisfying maximum service time requirements. Using this model framework, the research investigates the effect of service time requirements on the network flows and the hub network design.

In order to conduct the above mentioned analysis, this research develops a novel modeling framework and a solution methodology. Extending the multiple-allocation p-hub median approach to the intermodal logistics domain, the modeling framework accommodates the operational structure of individual modes of transportation, the effect of shipment consolidation at hubs on transportation costs, the interaction between modes, transit time delays and service time requirements. It also uses the fixed cost of locating the intermodal hubs and the modal connectivity cost as a tradeoff between opening new hub facilities and reducing the total transportation costs. The model compares the intermodal option with an OTR (over-the-road) option when selecting modal connectivity at the hubs. The modal connectivity cost is specified by the type of modes serviced at a specific hub.

The rest of this paper is organized as follows: Section 2 presents prior research in the intermodal logistics network domain and identifies the contributions of this work. Section 3 describes a modeling framework and a mathematical model for an intermodal logistics hub network. Section 4 presents a solution methodology which re-characterizes the original problem as an uncapacitated facility location problem and solves it using a tabu search meta-heuristic. This methodology is