Modeling Carrier Interactions in an International Freight Transport System

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ABSTRACT

This paper presents a novel multi-level hierarchical approach which models carrier interactions in international maritime freight transportation networks. Ocean carriers, land carriers and port terminal operators are considered. Port terminal operators, providing transportation services within a port complex, are regarded as a special type of the carrier, based on their behavior. The carriers make pricing and routing decisions at different parts of the multimodal network, having hierarchical relationships. Ocean carriers are regarded as the leaders in a maritime shipping market. Port terminal operators are the followers of ocean carriers as well as the leaders of land carriers. The individual carrier problem is formulated at each level using Nash equilibrium to find the optimal service charge and routing pattern for which each carrier obtains the greatest profit. Interactions among different types of carriers are captured in a three-level model. The concept of multi-leader-follower game is applied to a multi-level game. A numerical example is used to demonstrate the validity of the developed three-level model.

Keywords: Carrier Interactions, Freight Transportation Network, Game Theory, Multi-Level Hierarchical Game, Network Equilibrium Models

INTRODUCTION

In today’s global market place, setting competitive yet profitable service charges and minimizing costs, while providing good quality services, present major challenges to carriers. A set of carriers in international maritime freight transportation networks includes ocean carriers, land carriers and port terminal operators. Port terminal operators, providing transportation services within a port complex, are regarded as a special type of the carrier, based on their behavior. The carriers make decisions on prices and delivery routes (or port services) at different parts of the multimodal network, interacting with each other hierarchically. Ocean carriers typically transport freight between a departure and an arrival port terminal via waterways; port terminal operators handle freight within a port
complex; and land carriers transport freight between the port terminal and inland destinations.

Research efforts to forecast international freight movements via waterways emerged in the 1990s following the rapid growth of the maritime freight industry and the subsequent changes in the freight transportation system. To date, however, little attention has been paid to modeling maritime freight transport networks. A few models have captured interactions between shippers and ocean carriers or port terminal operators for international trade, assuming the behavior of the other carriers is known. Very few studies have considered relationships among different types of carriers. This paper proposes a predictive network model, which captures interactions among different types of carriers in a maritime shipping market using multi-level optimization programming.

The structure of the paper is as follows. The next section presents an up-to-date literature review of the existing models. The third section defines the research problem with the network structure and modeling approaches. The fourth section formulates individual carrier models and a three-level model. The fifth section develops a heuristic algorithm to solve the three-level model and the sixth section presents a numerical example to demonstrate the use and applicability of the model. The last section concludes the paper and suggests future studies.

LITERATURE REVIEW

Predictive network models forecast freight movements in the freight transport system by representing the transportation network explicitly. The models capture decisions and interactions of key stakeholders involved in freight transportation such as producers, consumers, shippers, carriers and governments, using the three common modeling methodologies: freight network equilibrium models, spatial price equilibrium models, integrated network equilibrium models (Harker, 1985; Crainic, 2002; Valsaraj, 2008). In addition, Nash equilibrium models and compensation principle models are also used to formulate alternative stakeholder behavior and decision making process (Wang, 2001; Zhang, 2008).

These modeling techniques have been used extensively in the freight modeling literature. Harker (1985) provides a good summary of research in this field up to 1985. Most of the models reviewed in his paper focus on one or two stakeholder problems considering shippers or/and carriers in the intercity freight transport system (Fang & Peterson, 1980; Florian & Los, 1982; Harker, 1983; Friesz et al., 1983; Freisz et al., 1984; Pang, 1984; Harker et al., 1986a; Harker et al., 1986b; Harker et al., 1986c; Dafermos & Nargune, 1987; Harker, 1988; Guelat et al., 1990; Miller et al., 1991; Hurley & Petersen, 1994; Fernandez et al., 2003; Agrawal & Ziliaskopoulos, 2006; Cheng, 2006; Yang et al., 2007; Xu & Holguin-Veras, 2009). Xiao & Yang (2007) studied relationships among three stakeholder groups such as one shipper, and multiple carriers and infrastructure companies. The models frequently used freight network equilibrium (Harker, 1988; Guelat et al., 1990; Hurley & Petersen, 1994; Fernandez et al., 2003; Agrawal & Ziliaskopoulos, 2006; Cheng, 2006; Xiao & Yang, 2007), spatial price equilibrium (Fang & Peterson, 1980; Florian & Los, 1982; Friesz et al., 1983; Freisz et al., 1984; Pang, 1984; Dafermos & Nargune, 1987; Xu & Holguin-Veras, 2009) and integrated network equilibrium (Harker, 1983; Harker et al., 1986a; Harker et al., 1986b; Harker et al., 1986c) approaches. Some used Stackelberg game (Miller et al., 1991; Yang et al., 2007) to analyze the multiple and sequential behavior of stakeholders on networks.

As the world maritime container traffic grew rapidly and significantly (BTS, 2010), several researchers started to study international maritime freight movements in the 1990s (Wang, 2001; Zhang et al., 2008; Kuroda et al., 2005; Zan, 1999; Min & Guo, 2010; Dimitriou & Stathopoulos, 2011). They captured sequential interactions between shippers and ocean carriers.
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