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A bilevel storage pricing model for outbound containers in a dry port system

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ABSTRACT

Serving as a potential solution for seaport congestion and capacity limitation, dry port development is increasingly popular in the freight transport industry. This paper pioneers the research on dry port operations by modelling the storage pricing problem for outbound containers. The interaction between a dry port and multiple shippers is modelled as a bilevel program. The optimal properties of the proposed model under certain conditions are derived analytically, from which a closed-form solution is obtained. Contrary to intuition, the increase of container delivery frequency from shippers may lead to the reduction of dry port's profit according to model outcomes.

1. Introduction

Dry ports have been proposed for relieving seaport congestions resulting from steeply rising container flows. A dry port is an inland logistics centre linked to or integrated with seaport(s), providing a cluster of shippers in an industrial/commercial region with public logistics services and auxiliary services including maintenance, customs clearance, and others. Some other terms have been used synonymously with dry port, including Inland Clearance Depot (ICD), Intermodal Freight Centre/Terminal, Freight Nodal Terminal, Inland Port, and Container Freight Station (CFS) (Beresford and Dubey, 1990; Roso et al., 2009). Well-established dry ports would benefit the inland transportation system by decreasing the transportation costs (Henttu and Hilmola, 2011); ameliorating the ecological environment by shifting transportation mode from road to rail (Lam and Gu, 2013; Roso, 2007); bringing benefits to seaports through securing hinterland market, reducing goods handling, and increasing berth throughputs; and offering high quality services to shippers and transport operators. Hence, dry ports have been widely implemented worldwide, typical examples of which include Eskilstuna Dry port in Sweden, Kansas City and Virginia Inland Port in US, Isaka Dry port in Tanzania, and Xi'an Dry port in China (Beresford et al., 2012; Roso and Lumsden, 2010).

This paper studies a hinterland supply chain which consists of one large volume dry port and multiple shippers located in close proximity to the dry port. This scenario is prevalent in practice. For instance, Virginia Inland Port, with a land area of 161 acres, serves 39 major companies located nearby including Ford Moto Co., GE Lighting, Mercury Paper, and many others (Edwards, 2013). In order to avoid low operations efficiency, a seaport only provides a temporary storage space for containers by charging a storage fee if containers' dwell time is longer than a free-time-limit. A dry port, however, charges a lower storage price than that in the seaport container yard. Hence, the dry port is more attractive for relatively long-term

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storage. An individual shipper first delivers containers to the dry port under an equal quantity, equal-interval delivery policy. Alternatively, containers may be delivered to the seaport directly. Many shippers have adopted such frequent and regular schedules in inland transportation. For example, companies in Charleston, West Virginia, use the daily rail service starting from early evening to transport containers to and from the inland port in Greer (Richardson, 2013). Frequent and regular shuttle services are run between the Paris region and Gennevilliers inland terminal (Frémont and Franc, 2010). After a storage duration, those stored at the dry port are moved to the container yard at the seaport terminal. Finally, all containers are loaded onto vessels.

The significance of this study can be seen from two perspectives. From the practical point of view, a dry port gains its main revenue by providing logistics services to shippers. It is natural that it must establish a suitable storage pricing strategy to attain the optimal profit. An exorbitant storage price at the dry port may drive shippers to use space at the seaport instead, which will increase pressure on seaport's capacity. In contrast, a too low price at the dry port may sacrifice the dry port's profit. Hence, a key challenge faced by the dry port is how to price its storage space. In response to the storage price, shippers enjoy the rights to determine what policy to adopt for transporting containers from their manufacturing plants to the dry port and the seaport. Therefore, shippers confront a common problem: how to optimally determine the delivery schedules in order to minimize their individual cost.

From the theoretical aspect, though the dry port concept has been studied extensively, the literature mainly lies in local and global case studies which investigate influencing factors of dry port development (Beresford et al., 2012; Notteboom and Rodrigue, 2005, 2009; Rodrigue et al., 2010; Roso and Lumsden, 2010; Roso et al., 2009). Very few quantitative studies exist for modelling dry port systems. Several papers have addressed the dry port location problems, aiming at exploring how to choose the optimal geographical location for dry ports to improve the transportation system more cost-efficiently (Racunica and Wynter, 2005; Rahimi et al., 2008). Moreover, there are a series of studies conducted on intermodal transportation with one or more dry ports, where dry ports are adopted for storage, consolidation/deconsolidation, and transshipment (Caris et al., 2013; Notteboom and Rodrigue, 2005). However, little attention has been paid on the operational aspects of storage space in dry ports.

With regard to storage pricing strategies, the research is very limited. de Castilho and Daganzo (1991) pioneer the study on storage pricing through addressing a pricing problem for temporary storage facilities at ports. Subsequent works are conducted on storage pricing strategies in different container port systems. Different from the above works which consider inbound container flows from seaport to shippers, this paper innovatively studies the storage pricing in a dry port system with outbound containers.

This paper aims at investigating how the dry port and shippers interact with each other to optimize their individual objective. The dry port determines the storage price to maximize its own profit, while each shipper determines the delivery schedules of containers to the dry port, and that from the dry port to the seaport, for the sake of minimizing its total cost. In this supply chain, the dry port is operated by a third-party logistics provider. The private or mixed (combination of private and public) ownership and private operation occur in a number of countries (Beresford and Dubey, 1990; Roso and Lumsden, 2010). As for shippers, they are autonomous and independent in making decisions. Thus, individual supply chain members have their own objectives and decisions to optimize. On the other hand, the decisions of dry port and shippers would impact each other's objective through sharing common parameters. More specifically, the following research questions are addressed.

(1) How does a dry port determine the storage pricing strategy?
(2) How do key parameters influence the dry port and individual shipper's decisions and performance?

To answer the first question, the bilevel programming approach (Calvete et al., 2011; Qiu and Huang, 2013) is adopted to model the problem. In this paper, the dry port is treated as the leader, and shippers as followers. The dry port first declares the storage pricing strategy. In response to it, each shipper determines the delivery schedules, while minimizing its overall cost. It is assumed that the dry port has complete information about shippers' cost parameters. Although dry port and shippers are "competitive" in the sense that they are autonomous and independent in making their own decisions, their relationship can also be considered as "cooperative". Shippers benefit from the improved logistics solutions provided by the dry port (Roso et al., 2009). Meanwhile, the dry port could also gain profit. In particular, a contract is made between the two parties so as to coordinate their efforts in improving their own performance. Therefore, under the contract, it is reasonable to make the above assumption. Then, taking into account of the response of each shipper, the dry port prices the storage space to maximize its own profit at the beginning. Furthermore, the analytical approach is adopted to derive the optimal decisions of both dry port and individual shipper under several further assumptions. To answer the second question, a number of sensitivity analyses are conducted with respect to various parameters, and their impacts are evaluated by a numerical study.

This paper is organized as follows. In Section 2, the relevant literature is reviewed. Section 3 formulates the bilevel model, which is then analysed and solved in Section 4. Section 5 presents a numerical study and corresponding sensitivity analyses to gain important managerial insights. Finally, conclusions are made in Section 6.

2. Literature review

The research literature related to this paper can be divided into two disparate streams: storage pricing strategies and logistics in dry port systems.