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Optimal unloading and storage pricing for inbound containers

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ABSTRACT

We study a terminal operator's optimal container unloading and storage pricing strategies. Unlike the existing literature that ignores the interaction between these two prices, we propose a novel model formulation where they are jointly determined to maximize total profit. Our results enable an efficient search for the optimal prices, and provide novel insights into the tradeoff between profit extraction and storage cost efficiency. We also formulate a model where the storage price is determined to maximize the storage profit only, and conduct an extensive numerical study to compare the two models to obtain additional insights about their performance.

1. Introduction

An ocean container terminal operation typically consists of two parts: One part is the unloading process of inbound containers, in which the containers are unloaded from a ship, transported to the yard area and stored in the blocks, while the other part is the loading process of outbound containers (Luo et al., 2011). According to Vis and Koster (2003), the inbound container handling process at a terminal consists of the following steps. When a container ship arrives at the terminal, quay cranes take the containers from the ship to vehicles that transport them to the stack at the terminal yard. These containers are temporarily stored at the stack and then retrieved by cranes and carried by vehicles to barges, deep sea ships, trucks or trains for transportation to other places. Thus, the handling of inbound containers at a terminal mainly includes unloading and storage services. Because of limited space, terminals usually offer only temporary storage space and customers who plan to store containers for extended time periods are expected to do so using an outside storage option. Such a temporary storage service is convenient to the customers and therefore commonly offered by terminals (Kim and Kim, 2007; Lee and Yu, 2012).

Nowadays, to meet the challenge of handling mega-ships capable of carrying 18,000 containers and beyond, a container terminal needs to improve the efficiency of the stacking and the transport of this large number of containers to and from the ship's side (Stahlbock and Voss, 2008). Academic researchers have been trying to investigate such problems, from operational levels (such as berth allocation, quay crane split and storage planning) or strategic levels (such as capacity development, risk management and pricing). More recently, there is a stream of work that focuses on studying storage pricing schemes at a container terminal. As far as we know, all of the papers on storage pricing consider the problem of finding the optimal storage price that maximizes the storage profit or minimizes the cost of storage service, whereas the impact of storage pricing on the profit generated by other services has not been considered. Holguin-Veras and Jara-Diaz (1999), who study the storage profit maximization problem, comment that a more comprehensive pricing framework encompassing the other service processes would be very valuable for terminal management. Fransoo and Lee (2013) point out that high storage prices would turn customers away to competing terminals, whereas low storage prices would transfer quay into cheap warehouse space and reduce terminal efficiency. Obviously a terminal would lose profit

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derived from other services when customers are turned away to competing terminals. As we have discussed earlier, unloading and storage are two services commonly offered by a container terminal for inbound containers. When we discussed these issues with managers of the Hongkong International Terminals Limited, a major global terminal operator, they pointed out that the unloading and storage prices are usually jointly determined for inbound containers. Motivated by this gap between academic research and industrial practice, we study the terminal operator's unloading and storage pricing problem and hope to shed light on the following research questions. How to jointly determine the optimal unloading and storage prices to maximize the total unloading and storage profit for inbound containers? What are the tradeoffs in determining these prices? When will the storage profit maximization formulation and the joint profit maximization formulation lead to the same optimal prices? The last question is important because we want to understand under what conditions the results of the existing storage pricing literature (under the objective of maximizing only storage profit) can be applied to practice without loss of optimality.

We consider a terminal operator that offers unloading and storage services for inbound containers. The shippers are the customers who decide whether to call at the terminal and, if so, whether to store containers at the terminal yard or at a remote yard.[1] To store at the remote yard, the customer needs to pay a fixed cost in transporting a container from the terminal yard to the remote yard, and a storage fee per unit time for storing the container there. The terminal operator seeks to determine the unloading and storage prices for his services. Customers are homogeneous in service valuation but have different dwell times (i.e. the time for storing their containers). We formulate two profit maximization models for the terminal operator's pricing problem. In the joint profit maximization (JPM) model, the operator jointly determines the unloading and storage prices to maximize the total unloading and storage profit. In the storage profit maximization (SPM) model, the operator determines the storage price to maximize the storage profit for a given unloading price, and determines the unloading price to maximize the total unloading and storage profit. The second formulation is motivated by how the storage pricing problem has been formulated in the existing literature. As explained earlier, one of our goals is to compare the two models to understand the limitation of the formulation that the storage price is determined to maximize only the storage profit, whereas in practice the unloading and storage prices are jointly determined.

For the JPM model, we first show that the joint optimization problem can be solved by determining the prices sequentially. Given an unloading price, we fully characterize the optimal storage price that maximizes the total profit. This allows us to conduct a one-dimensional search for the optimal unloading price for solving the joint optimization problem. Our results reveal how the optimal prices depend on the tradeoff between profit extraction and storage cost efficiency. When it is not efficient for the customers to store containers at the remote yard, the terminal operator could use a very low storage price to encourage customers to call at the terminal, and use an unloading price to extract as much profit as possible from all the customers because they have homogeneous service valuation. Otherwise the terminal operator needs to charge a higher storage price to induce customers with a long dwell time to use the remote yard storage option, which improves storage cost efficiency. However, when the storage price is higher, the customer's unloading net value (i.e. willingness to pay minus customer storage cost) becomes more heterogeneous. As a result, under a fixed unloading price, the operator has to leave more surplus to the customers. Thus it lowers the operator's ability in using the unloading price to extract profit from the customers. For the SPM model, given an unloading price, we fully characterize the optimal storage price that maximizes the storage profit. Again, this result allows us to conduct a one-dimensional search for the optimal unloading price that maximizes the total profit. Our analytical results provide insights into when the optimal storage prices are the same under both models. We also show that the storage price under the JPM model cannot be higher than that under the SPM model.

We conduct an extensive numerical study to illustrate the results and to obtain more insights. We identify two sets of conditions under which the optimal prices and profits behave differently. For one set of conditions, for the JPM model, the terminal operator would charge a relatively low unloading price to create a high demand to the terminal, and use the storage price to induce customers with a long dwell time to use the remote yard storage option. Moreover, both the optimal prices and the total profits under the JPM and SPM models are the same. This reconciles the limitation of the SPM formulation in practice. For another set of conditions, for the JPM model, the terminal operator would charge a very low storage price to attract customers who would only have used unloading service but stored containers at the remote yard, and at the same time he would charge a high unloading price to extract as much profit as possible. The optimal prices under the two models are now different, and the profit foregone due to the SPM formulation could be quite substantial.

The remainder of this paper is organized as follows. Section 2 reviews the literature. Section 3 provides the problem description and some preliminary analysis. Sections 4 and 5 respectively formulate the JPM and SPM models, and characterize the corresponding optimal storage price when the unloading price is given. Section 6 presents the numerical study. Section 7 offers concluding remarks. All the proofs of the propositions are included in Appendix A.

2. Literature review

There is extensive research on ocean container terminal operations. The relevant areas include berth scheduling, crane assignment, truck arrival management, stack configuration, storage space allocation and so on. In most cases analytical or simulation models are used to solve the problems. Comprehensive literature reviews can be found in Vis and Koster (2003), Steenken et al. (2004), Gunther and Kim (2006), and Stahlbock and Voss (2008). Kim and Lee (2015) introduce current trends of and new challenges

[1] Most studies on port choice examine the decision from the point of view of the shippers, because they are the people who actually make the decision to route cargo through a port (Tongzon, 2009). The shippers choose a port based on factors such as port location, port geography, and operational capabilities (Panayides and Song, 2012).