European Journal of Operational Research 245 (2015) 470–479

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Production, Manufacturing and Logistics

# Capacity reservation for time-sensitive service providers: An application in seaport management

L. Jeff Hong[a], Xiaowei Xu[b], Sheng Hao Zhang[c,*]

[a] Department of Economics and Finance and Department of Management Sciences, City University of Hong Kong, Tat Chee Avenue, Kowloon Tong, Hong Kong, China

[b] Department of Supply Chain Management and Marketing Sciences, Rutgers, The State University of New Jersey, Newark, NJ 07102, USA

[c] Department of Industrial Engineering, School of Management, The Key Laboratory of the Ministry of Education for Process Control and Efficiency Engineering, Xi'an Jiaotong University, Xi'an 710049, China

ARTICLE INFO

*Article history:*
Received 26 May 2013
Accepted 20 March 2015
Available online 28 March 2015

*Keywords:*
Capacity management
Pooling
Seaport management
Time-sensitive demands
Frequency competition

ABSTRACT

This paper analyzes a capacity management problem in which two service providers utilize a common facility to serve two separate markets with time-sensitive demands. The facility provider has a fixed capacity and all parties maximize demand rates. When the service providers share the facility, they play a frequency competition game with a unique Nash equilibrium. When the service providers have dedicated facilities, the facility provider leads two separate Stackelberg games. A centralized system with the first-best outcome is also examined. Based on closed-form solutions under all three scenarios, we find that facility capacity competition is a prerequisite condition for not pooling the service providers. Moreover, we establish the rankings of preferred strategies for all parties with respect to the ratio of the service providers' demand loss rates, which are proportional to the time sensitivity of demand and the potential market size. Interestingly a triple-agreement situation for the pooling strategy exists if the rates are close, and the facility provider permits a request for dedicated facilities only if the service provider has an overwhelming dominance at the demand loss rate. We connect these managerial insights with strategic seaport capacity management.



## 1. Introduction

Many service systems involve with multiple parties and increasing the service capacity of one service provider may not help improving the overall service system performance. For instance, a maritime system includes carriers and port authorities. Since a seaport has a limited capacity in processing vessels, a carrier may not be able to shorten the cargo delivery time when pushing the vessel frequency close to the port's handling capacity. Moreover, the bottleneck of public logistic facilities becomes severe when multiple service providers compete on a fixed amount of facility capacity. It is well known that a user of a public resource often ignores the negative externality that she/he imposes on other users (Hardin, 1968). This ignorance can cause congestion and massive losses in many logistic systems. For example, Ball, Barnhart, Dresner, Hansen, Neels, et al. (2010) estimate that the total cost of US domestic air traffic delays is around $31.2 billion for calendar year 2007. One way to solve this issue is to use incentive-compatible pricing schemes (see Ha, 1998; Mendelson & Whang, 1990), which have been widely adopted by public transportation authorities. Another way is to allocate dedicated facilities to certain types of users, which is commonly practiced by port authorities and is the focus of this paper.

A strategic problem for a port authority is to decide whether to pool all carriers together to share the port facilities or to allocate dedicated facilities to individual carriers. When a port pools the vessels from all carriers together and fully utilizes its facilities, this pooling effect generally leads to more efficient usage of the facilities. However, the pooling strategy is not perfect for the port. When carriers are put together, they may compete for the port facilities by increasing the vessel frequency in order to provide better service for their customers. This competition effect may result in congestion and offset the benefit of the pooling effect. Since using dedicated facilities separates the operations of different carriers, this reservation strategy eliminates the competition effect as well as the pooling effect. From carriers' perspective, a busy port may cause long and unpredictable time delays, which often cause a loss to carriers as their customers are usually sensitive to the time spent on the transportation route. To reduce the time delay and avoid competition with other carriers for port facilities, carriers are inclined to having dedicated port facilities. Hence, it is important for both a port authority and carriers to

* Corresponding author. Tel.: +86 15829361566.
*E-mail addresses:* jeffhong@cityu.edu.hk (L. Jeff Hong), xiaoweix@andromeda.rutgers.edu (X. Xu), shhzhang@mail.xjtu.edu.cn (S.H. Zhang).

http://dx.doi.org/10.1016/j.ejor.2015.03.027
0377-2217/

understand the tradeoff between pooling and reservation strategies and the interactions among their capacity decisions.

This paper studies a three-tier model, where a facility provider (a destination seaport) offers its facility to two service providers (carriers), who ship customers' cargos from two different origin ports to the same destination port. We assume that customer demand rate on each route decreases linearly in the total transportation time spent at the origin and destination ports and all parties maximize their cargo volumes. Three scenarios are considered. In the first scenario, the facility provider adopts the pooling strategy. The service providers determine their service capacity levels and compete for facility usage. We find a unique Nash equilibrium for this scenario. In the second scenario, the facility provider allocates facility capacity to each service provider, who determines the service capacity given its dedicated facility capacity. Finally, in the third scenario, we study the first-best outcome of a centralized system, in which a central planner jointly chooses the facility capacity management strategy and the service capacity levels. Based on closed-form solutions under all three scenarios, our study identifies conditions under which the facility provider and service providers should adopt the pooling or reservation strategy.

Our work contributes to the literature on capacity pooling and reservation strategies, which will be reviewed in the next section, in the following aspects.

First, we assume that both the facility provider and service providers maximize their demand rates, as cargo volume is one of the most important performance measures in the maritime industry (see Stopford, 2009; World Bank, 2007, p. 85). A port authority run by a local government weights much more on the economic contribution of cargo traffic to the local economy than its own profitability. A long-distance oversea shipper needs to defense its market share when its clients have an expensive alternative of air shipping. This distinguishes our model from many works on time-sensitive demands, in which pricing is often the central concern. Moreover, we pay attention to the case where two service providers face separate markets. Hence our model avoids the complexity introduced by market competition between two service providers, which is often the main theme of literature on time-based competition. By focusing on capacity management from an operational perspective, we find that pooling is always optimal under the centralized system, which suggests that facility capacity competition is a prerequisite condition for not pooling the service providers.

Second, our three-tier model allows time-sensitive customer demands depending on the transportation time spent at both the origin and destination ports. Notice that increasing the shipping frequency on a route decreases the time that cargo spends at the origin port but increases the time that vessels spend at the destination port of the route. When sharing the common facility capacity, self-interested service providers ignore the negative externality of their frequency decisions on others and cause facility over-utilization. Essentially our model under the pooling strategy examines a frequency competition between two service providers on the common facility capacity and hence contributes to the literature on frequency competition.

Third, we find that the facility provider's optimal choice between the pooling and reservation strategies critically depends on the ratio of the demand loss rates of two service providers. The demand loss rate is proportional to the potential cargo volume and the time sensitivity of demand on a route. Our result complements observations in the queueing literature that pooling is not optimal if customer characteristics, such as service time distributions and time sensitivity, are significantly different. Furthermore, we show that dedicated facilities are not always preferred by service providers and their optimal choices are also determined by the ratio of the demand loss rates of two service providers. This view is missing in the queueing literature, which only concern about the optimal choice of the facility provider.

Finally, in reality, the allocation of the facility provider's capacity is often done with service providers through tough negotiation processes, which may involve many other economy factors, for example, port charges, long-term relationship, etc. No matter how complex these processes are, all players have to understand the tradeoff between pooling and reservation strategies from an operational perspective, which is exactly the focus of our work. The managerial insights developed in this paper, e.g. the rankings of their preferred strategies and the existence of the triple-agreement situation, help all players to understand the interactions among their capacity decisions and lay down a sound foundation upon which to incorporate other factors in the tradeoff between pooling and reservation strategies.

The rest of the paper is organized as follows. In Section 2, we provide a brief review of related literature. The model is introduced in Section 3. Then, we study the pooling strategy, the reservation strategy and the centralized system in Section 4. We make comparisons between the pooling and reservation strategies in Section 5 and draw conclusions in Section 6. All proofs are relegated to the online supplements of the Appendix.

## 2. Literature review

The tradeoffs between capacity pooling and reservation strategies have been studied from many different perspectives. We briefly review the literature from four aspects below.

### 2.1. Queueing systems

It is well know that combining separate subsystems into one system may improve the overall system efficiency, since the combination reduces the chance of idleness of subsystems and generates economies of scale. However, if customers have heterogenous characteristics, then merging queues may be counterproductive. Smith and Whitt (1981) and Whitt (1999) show that if customers fall into classes with different service time distributions, then keeping different types of customers into separate queues may be optimal. Yu, Benjaafar, and Gerchak (2015) study a capacity sharing problem among a set of independent queues. They find that capacity pooling may not be optimal if the workloads of queues are significantly different. Rothkopf and Rech (1987) provide other reasons of not merging queues. van Dijk and van der Sluis (2009) propose rules to further reduce average waiting time under both pooled and unpooled scenarios for two customer groups with different service time distributions.

The preferred choice between pooling and reservation strategies highly depends on the congestion caused by negative externalities that a user imposes on other users in queueing systems. Haviv and Ritov (1998) derive measures of such negative externalities under different queue disciplines. Osorio and Bierlaire (2009) explain the propagation of congestion. Mendelson and Whang (1990) and Ha (1998) develop incentive-compatible pricing schemes to regulate the negative externality effects. Our model demonstrates under what market conditions the pooling benefit dominates (is dominated by) the negative impact of facility capacity competition for both the facility provider and service providers.

### 2.2. Time-sensitive demands

When customer utility or demand is time sensitive, capacity pooling and reservation strategies can serve as market segmentation tools. For instance, Pangburn and Stavrulaki (2008) study a joint pricing and capacity management problem and find that capacity pooling is suboptimal if customers are heterogenous in their time sensitivity. Our model reveals that another customer characteristic, the potential market size, also affects the pooling decision.

However, most studies consider profit-maximizing problems with pooled service capacity under various settings. Since we focus on capacity management from an operational perspective, we only review a few studies and refer to them for a more comprehensive review.