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Original Research Paper

Joint slot allocation and dynamic pricing of container sea–rail multimodal transportation

Di Liu [a,b], Hualong Yang [a,*]

[a] College of Transportation Management, Dalian Maritime University, Dalian 116026, China

[b] College of Traffic and Transportation Engineering, Dalian Jiaotong University, Dalian 116028, China

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ABSTRACT

The container sea–rail multimodal transport system faces complex challenges with demand uncertainties for joint slot allocation and dynamic pricing. The challenge is formulated as a two-stage optimal model based on revenue management (RM) as actual slots sale of multi-node container sea–rail multimodal transport usually includes contract sale to large shippers and free sale to scattered shippers. First stage in the model utilizes an origin-destination control approach, formulated as a stochastic integer programming equation, to settle long-term slot allocation in the contract market and empty container allocation. Second stage in the model is formulated as a stochastic nonlinear programming equation to solve a multiproduct joint dynamic pricing and inventory control problem for price settling and slot allocation in each period of free market. Considering the random nature of demand, the methods of chance constrained programming and robust optimization are utilized to transform stochastic models into deterministic models. A numerical experiment is presented to verify the availability of models and solving methods. Results of considering uncertain/certain demand are compared, which show that the two-stage optimal strategy integrating slot allocation with dynamic pricing considering random demand is revealed to increase the revenue for multimodal transport operators (MTO) while concurrently satisfying shippers' demand. Research resulting from this paper will contribute to the theory and practice of container sea–rail multimodal transport revenue management and provide a scientific decision-making tool for MTO.

1. Introduction

This paper addresses the challenges of joint slot allocation and dynamic pricing in container sea–rail multimodal transport system based on revenue management (RM). Container sea–rail multimodal transport is an advanced transportation form with advantages of high efficiency, fast speed, large capacity, low cost, and minimal pollution. As organizers for container sea–rail multimodal transport, the multimodal transport operators (MTO) typically contract with actual

* Corresponding author. Tel./fax: +86 411 84728392.

E-mail addresses: liudi@djtu.edu.cn (D. Liu), hlyang@dlmu.edu.cn (H. Yang).

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freight carriers (railway companies and liner companies) to purchase operational rights for a certain numbers of capacity slots as capacity resource. Slots are then sold to shippers by the MTO with charges based on total freight. If the MTO sell all the slots at a unified price and on a "First Come First Served", higher returns would be forfeited, as profits from later shippers, willing to pay a premium for shipping privileges, are lost. Optimal decisions for slot allocation and pricing in the process of slots sale are then vital to maximize profits as well as cope with the different container transportation demands.

In the field of container multimodal transportation, research focused on slot allocation and pricing is scarce with most studies focused on network planning and path optimization (Chang, 2008; Chang et al., 2010; Fan et al., 2010; van Riessen et al., 2013; Ziliaskopoulos and Wardell, 2000). Recently, slot allocation and dynamic pricing based on RM have attracted more attention in single mode of container transportation. Lee et al. (2007, 2009) presented a stochastic dynamic programming model for a single leg revenue management problem. Feng and Chang (2010) studied the optimal slot allocation problem of a liner on specific routes taking into account the cost of empty container allocation. Lu et al. (2010) utilized a quantitative slot allocation model to maximize potential profit per service, taking into account demand, empty container repositioning restrictions, slot size, loaded weight and reefer capacities. Zurheide and Fischer (2011) studied the discrete simulation of liner slot booking, and established liner slot allocation quantitative models taking the transfer possibilities among multi sections and multi routes into account, which was simulated in different situations, networks and input settings to determine the optimal slot booking strategy for shipping companies. Cao et al. (2012) formulated the stochastic integer programming model for the capacity allocation problem taking into account matches in supply and random demand of rail container transportation. In the works of Yin et al. (2010), a nonlinear pricing revenue optimization model was conducted based on a classical two-part pricing theory. Yin and Kim (2012) discussed a method of optimizing container lines' freight tariffs through consideration of changes in order quantities made by freight forwarding responding to price schemes proposed by the container lines companies. Bu et al. (2012) studied option contract ordering and the pricing policy of freight forwarding considering empty container repositioning issues.

Research has been mostly limited to single mode of container transport (shipping or railway) with minimal related research focused on container sea–rail multimodal transport. The sea–rail multimodal transport is unique from single mode of transport as combining shipping and railway dramatically increases RM complexities. Background research generally assumes a back and forth route formation for single mode of transport, while circular routes typical in shipping have not received equivalent focus. The circular routes in shipping will lead to a more complex segments combination and goods flow in sea–rail multimodal transport. Additionally, while research for single decision-making behavior (capacity/slot allocation or pricing) is ample, research for unified decision-making required for slot allocation and dynamic pricing of container transport is scare.

Slot allocation and dynamic pricing are generally regarded as technologies related to inventory control and dynamic pricing in RM and have been separately studied for decades (Belobaba, 1987; Brumelle and McGill, 1993; Feng and Gallego, 1995; Feng and Xiao, 2000; Gallego and van Ryzin, 1994; Littlewood, 1972; van Ryzin and McGill, 2000; Zhao and Zheng, 2000). Inventory control and dynamic pricing interact closely with each other, thus should be analyzed integratively. Research has been conducted on this topic. Weatherford (1997) advanced a comprehensive RM model of pricing and capacity control, and discovered that price should be included as a decision variable in the comprehensive model as demand is affected by price. Accuracy of the model is not achieved however, as a result of the complex expression of income function. Feng and Xiao (2006) studied the comprehensive decision model for optimal capacity allocation and dynamic pricing, discovering that optimal capacity allocation and pricing strategy is based on a threshold point sequence which is a function of inventory, price and strength of demand. Taudes and Rudloff (2012) proposed an integrated pricing and inventory control model with a two-period linear demand model, proving that optimal joint pricing/inventory policy for the replenishment opportunity, following the first period, is a base-stock list-price policy. Zhu (2012) studied a single-item periodic-review model for the joint pricing and inventory replenishment problem with returns and expediting. Lee (2014) studied a periodic-review pricing and inventory replenishment problem with stochastic demands in multiple periods, concluding that optimal price is determined based on inventory level after the replenishment in each period.

The above research focused on joint capacity control and dynamic pricing decisions, but was limited to general perishable products or air passenger transport. Additionally, research focused only on single product (or single flight segment transport) under predictable or random demand. Joint capacity control and dynamic pricing, as related to container sea–rail multimodal transport with multi-segment transport under random demand, will significantly benefit from focused research efforts.

In a word, it can be attested that no studies deal with a comprehensive research process for four components simultaneously including: container sea–rail multimodal transport issues, joint decision of slot allocation and dynamic pricing, multi-node line (multi-product) and random demand. Different from the existing research, we combine the four components together and establish a two-stage optimal model. First stage of the model seeks to solve long-term slot allocation based on contract sale and empty container allocations by applying an origin-destination control equation. Second stage of the model seeks to determine pricing and slot allocation in each period of free sale by applying a multi-product joint dynamic pricing and inventory control approach. Challenges develop as random demand increases difficulty of solving the models, thus we use the methods of chance constrained programming and robust optimization to transform stochastic programming into deterministic programming. A numerical experiment is then presented to verify accuracy of the models and solution methods. Contributions will be produced by this research to enhance the theory and practice of container sea–rail multimodal