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RESEARCH PAPER

Dynamic Pricing Model of Container Sea-Rail Intermodal Transport on Single OD Line

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Abstract: In the management of container sea-rail intermodal transportation, dynamic pricing problem with uncertain conditions has significant impacts on the benefit and competitiveness of a multimodal transport operator. Based on the revenue management theory and the features of container sea-rail intermodal transport, this paper develops a two stages optimal model which integrates dynamic pricing and slot allocation on single origin-destination line. The first stage is proposed by considering long-term slot allocation in contract market, and the second stage is set up in consideration of the dynamic pricing in free market. Because of the demand uncertainty and the statistic error characteristics, the method of chance constrained programming and a robust optimization model are used to solve the models, respectively. The simulation shows the feasibility and efficiency of the proposed models and algorithms.

Key Words: integrated transportation; dynamic pricing; revenue management; container; sea-rail intermodal transport; optimal model

1 Introduction

Due to its high efficiency, fast speed, large capacity, low cost, less pollution, and other outstanding advantages, container sea-rail intermodal transport becomes the focus model promoted by the integrated transport system in “the 12th Five-Year” National Plan. The relevant departments, such as government, railways, ports, and shipping companies, are actively making improvements and co-ordinations to container sea-rail intermodal transport from the aspects of management system, infrastructure, and operational organization. Thus, the development of the environmental and technical condition for container sea-rail intermodal transport will be gradually improved, and the market demand will grow with diverse characteristics, which will result in an enormous challenge to MTOs. Container sea-rail intermodal transport has the typical characteristics of applying the revenue management theory, such as the transport capacity in a certain period of time is fixed; transport services cannot be stored with perishability, but can be pre-sold; fixed cost is high, and marginal cost is low; market demand can be segmented, but is volatile. Therefore, employing revenue management ideas in the container sea-rail intermodal transport system is feasible. How to use the revenue management theory to respond to intermodal market demand changes flexibly and to increase transport efficiency and effectiveness are important decisions related to the future survival and development of MTOs.

Domestic as well as foreign scholars have conducted a lot of researches on container transport revenue management. Ha[1] has studied the slot control strategies of a container shipping company using the expected marginal revenue (EMR) and threshold curve (threshold calve) model; Feng *et al*.[2] have studied the optimal slot allocation problem of a container liner on specific routes by taking the cost of an empty container allocation into account, and established a mathematical programming model with the objective of maximizing liner companies’ operating profits, and the constraints on shipping capacity, container demand, and the supply of empty containers; Sebastian[3] has studied the discrete simulation of liner slot booking, and established liner slot allocation quantitative models with taking the transfer possibilities among multi sections and multi routes into account, which were simulated in different situations,

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networks, and input settings to determine the optimal slot-booking strategy for shipping companies; Pu[4] has established a series of mathematical models based on the container liner slot allocation problem with stochastic programming and dynamic programming methods in his Ph.D. thesis, and solved the models with chance-constrained programming and robust optimization methods; Yang *et al*.[5] conducted quantitative research on the pricing of container liner slots, and established a slot pricing model with the objective of maximizing the expected return and the constraints that demands obey Poisson distribution and shippers' reservation prices obey exponentially distribution, then got the optimal slot pricing equation and analyzed the nature of the optimal price; Ren[6] has studied the pricing problem of China Railway Container Transport in his master's degree thesis, and established a railway container transport pricing model without considering empty container allocation, then simulated, and analyzed the impacts of transport costs, differences of shippers' subjective value, shippers' arrival rate, and initial slot changes on the optimal pricing and the maximum expected return.

As mentioned above, existing literatures only focus on container transport revenue management of a single mode of transport (by sea or rail transport) from the perspective of a particular decision-making behavior (eg, capacity or slot allocation decisions, dynamic pricing decisions); however, the research on container sea-rail intermodal transport revenue management and the comprehensive decision making of slot allocation and dynamic pricing is still rare. Based on the business and organizational characteristics of container sea-rail intermodal transport, this article integrates the pricing strategy with slot allocation by considering the pricing differences between contract sale and free sale as well as the dynamic pricing during the free sale period from the MTOs' point of view, and establishes the dynamic pricing model of container sea-rail intermodal transport based on revenue management in order to enrich the theory and practice of container sea-rail intermodal transport revenue management and to provide a scientific decision-making tool for the operational management of MTOs.

2 Modeling

2.1 Problem description

It is assumed that an MTO enterprise in an imperfectly competitive market has a monopoly pricing power. Based on the container sea-rail intermodal transport demand between A and B, the MTO decides to operate a container sea-rail intermodal transport line between A and B as the Origin-Destination point (O-D). The MTO selects port P as the seamless transferring port of rail and sea through a path selection decision; determines a railway company and a liner company as the actual carriers of railway and maritime sections through a sub-carrier selection decision; then signs a long-term agreement with the actual carriers; and, finally, gets the operational right of the same amount of slots in both railway container trains between A and P and shipping container liners between P and B, so as to ensure a stable capacity as well as the reduction of operating costs. In the agreement period, the MTO will sign sea-rail intermodal transport contracts with shippers as a contract carrier and charge for total freight at a single rate to organize the container sea-rail intermodal transport. In order to adapt to market competition and increase efficiency and effectiveness, the MTO needs to formulate a reasonable pricing strategy and a slot allocation strategy for different transport demands.

Since the demands of container sea-rail intermodal market between A and B is in a one-way direction, the MTO controls slots sale at the originating point, that is to say, the MTO sells slots at A and B separately. The selling process can be divided into two stages: In the first stage, the MTO sells a part of the slots in advance according to the requests of large customers, which are manifested as a series of sale contracts; in the second stage, the MTO sells the remaining bit of slots freely at public price according to demand forecasting, and accepts the booking from a variety of scattered customers.

In the first stage, the intermodal price for contract customers who have a strong bargaining power is certain; thus, the MTO needs to decide how many slots at most can be allocated to these contract customers at a negotiated price to make maximum revenue. In the second stage, since scattered customers who do not have bargaining power have to book slots at the public price announced by the MTO, the MTO may divide freight solicitation time T into t periods and determine the intermodal price and slot allocation in each period, respectively, according to the forecast of demands to make maximum revenue. The revenue management problem of the MTO is depicted in Fig. 1.

2.2 Model

The objective in the first stage is to determine the appropriate slot number for contact sale to maximize the revenue of the MTO, as the model (M1)

$$\text{Objective:}\quad \max z = p^{\mathrm{I}} \cdot x^{\mathrm{I}}$$

$$\text{s.t.}\ \begin{cases} x^{\mathrm{I}} \le D^{\mathrm{I}} & \text{①} \\ x^{\mathrm{I}} \le C & \text{②} \\ x^{\mathrm{I}} \in N \cup \{0\} & \text{③} \end{cases}$$

where x^{I} is a decision variable that represents the slot number allocated to contract customers for contact sale; D^{I} represents the random demands of contract customers; p^{I} indicates the negotiated price for contract customers; C represents the total slot capacity of the intermodal line.

Constraint ① shows that the slot number for contact sale cannot be greater than the random demands of contract customers; constraint ② expresses that the slot number for