Journal of Rail Transport Planning & Management 5 (2015) 1–11

Contents lists available at ScienceDirect

Journal of Rail Transport Planning & Management

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

Combinatorial auctions of railway track capacity in vertically separated freight transport markets

April Kuo [a,*], Elise Miller-Hooks [b,1]

[a] Manager Operations Research & Advanced Analytics, Capacity Planning & Operations Research, BNSF Railway Company, United States
[b] Department of Civil and Environmental Engineering, 1173 Glenn Martin Hall, University of Maryland, College Park, MD 20742, United States

ARTICLE INFO

Article history:
Received 31 July 2013
Revised 10 December 2014
Accepted 18 December 2014
Available online 10 January 2015

Keywords:
Combinatorial auctions
Spot markets
Intermodal freight transport
Rail transport
Train service base planning

ABSTRACT

This paper addresses the problem of allocating residual track capacity among multiple competing carriers where infrastructure ownership and train operations are vertically separated to facilitate delivery by train. Two bid set construction techniques are proposed that allow carriers to fully express their preferences for track usage. Both techniques enable the expression of complementary or substitutable relationships among the train slots constructed along predetermined train routes and permit quick configuration of routes from residual track capacity along which new trains can be operated. A winner determination problem that simultaneously accommodates bidding languages of both bid set construction techniques is used to generate an optimal capacity allocation among bidders based on different bidding strategies. Results of computational experiments designed to illustrate the efficiency of the proposed bid construction technique and effectiveness of the framework are presented.

1. Introduction

One-off-loads arriving on the freight transport market at irregular points in time, such as might originate from companies with highly irregular production and shipment schedules, can be carried by truck, rail, ship or air. These shipments are often time-sensitive. To compete for the shipments, rail companies need to be flexible. In some instances, it may be possible to add capacity to existing trains. However, it is often the case that such added capacity is precluded by length and locomotive limitations. For example, train lengths are limited by the capacities of the sidings. Thus, in planning for such shipments, rail companies schedule additional trains within the residual capacity that remains after serving more reliable forward contracts, and cancel or combine these trains as final shipment orders are realized. This paper focuses on the handling of these one-off loads by rail through the creation of these additional, new trains.

In rail networks in which excess track capacity is abundant, inefficiencies in constructing slots for such new train lines as required can be tolerated. When such excess track capacity is scarce, as may be the case in highly congested systems, efficiency and flexibility in residual capacity utilization is critical if desired service levels are to be achieved.

To schedule a new train in some regions of the world, carriers must apply to an track owner for track access rights to operate trains in a chosen rail corridor. This is the case in Europe where these rights are retained by national governmental agencies. Infrastructure ownership and train operations in the majority of the North American continent are vertically separated. In these contexts, typical goals of the track owner in allocating track capacity are to create economic efficiency and greater competition and to meet social obligations of provided services. See Affuso (2003) for related discussion pertaining to such vertical separation in Italy. Rail operations differ in the United States (U.S.), where infrastructure management and train operations are vertically integrated and the objective is to maximize profit.

The problem of allocating residual track capacity among multiple competing carriers where infrastructure ownership and train operations are vertically separated to facilitate the delivery by train of one-off loads in a given time period is addressed herein. Fig. 1 illustrates the process of allocating residual track capacity to trains that can carry these shipments over a multi-period time-scale where it is assumed that carriers have information on their shipments' preferred delivery times and origin–destination (O–D) pairs.

The application to the authority is made in the form of bids for track access rights. A bid consists of the specification of a set of

* Corresponding author.
E-mail addresses: April.Kuo@BNSF.com (A. Kuo), elisemh@umd.edu (E. Miller-Hooks).
[1] Tel.: +1 301 405 2046

http://dx.doi.org/10.1016/j.jrtpm.2014.12.001
2210-9706/

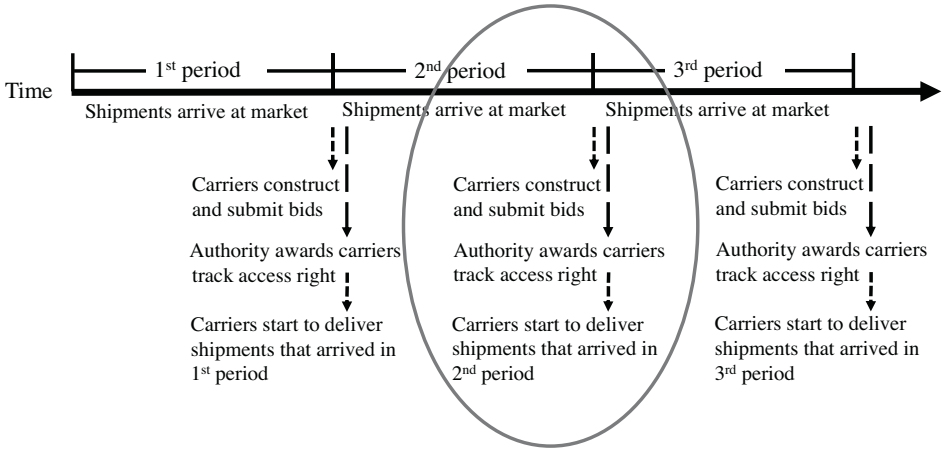

Fig. 1. Issuance of residual track capacity to trains carrying shipments arising on the spot market.

contiguous track segment-time pairs (i.e. train slots), shipments that will be transported within the train slots, and a monetary amount that the carrier is willing to pay for rights to these train slots. Each train slot may support a train carrying shipments between multiple O–D pairs along the associated route. How a carrier constructs a bid is dependent on: (1) residual capacity within a service network, (2) shippers' preferred delivery times, and (3) revenue to be gained by operating a train along the train slot. For simplicity, it is assumed that each container incurs the same revenue.

Often, more than one carrier will bid for track access rights to the same train slots, as operational areas of competing carriers may overlap. Thus, the authority must decide how to issue limited track capacity among competing carriers. Such rights are granted to carriers through an award process. Once track access rights are awarded, the carriers assign their shipments to the newly composed trains based on shipment O–Ds and shipper specified preferred arrival and departure times. This process is depicted in the oval outlined portion of the Fig. 1.

Carriers must efficiently identify train slots upon which to bid. The creation of bids to pose to the granting authority can be a difficult process when the number of containers is large and the shipment O–Ds and desired arrival times are diverse. This is of particular concern when the carrier provides service over multiple corridors with shared track capacity. Additional benefits can be derived where bid creation permits a carrier's preferences and expert knowledge to be reflected in the train slot formation process.

Two bid set construction procedures are proposed herein: the all-or-nothing and train slot-based bid set construction approaches. Both approaches permit bidders to fully express their preferences for combinations of train slots. The second approach, however, produces a more compact final bid set. Suppose the carrier wishes to obtain two train slots between a given O–D pair, one with a morning delivery and the second associated with an evening delivery. And suppose train slots A and B meet the needs of the morning delivery and C and D meet the needs of the evening delivery, although routes associated with B and D are longer than those associated with A and C. By the all-or-nothing construction approach, all combinations of bid sets containing a morning and evening train slot would be enumerated and proposed in the auction. By the latter construction approach, a single OR-of-XOR bid would be proposed. This bidding structure permits the awarding of only a morning or evening train slot, as well.

To model the problem of optimal bid allocation, a Winner Determination Problem (WDP) is formulated that supports both bidding constructs simultaneously. The objective of the developed WDP is to issue track access rights among the carriers such that selected social benefits, i.e., carrier competition and number of shipments delivered, are maximized. One might choose an alternative objective of maximizing profit, where track access rights to a given rail network are provided by a private infrastructure owner operating its own fleet. In vertically integrated markets, such as in the U.S., it may be beneficial for such a rail company to grant access rights for excess track capacity to its competitors, enabling rail service provision to new markets and customers. Since freight rail companies in the U.S. do not create conflict-free schedules for trains, train slots generated through the use of the proposed framework can provide such a base plan.

Bid set construction and bid allocation concepts proposed herein are illustrated numerically on a network that captures many related important complexities that would arise in a real-world application.

2. Literature review

Combinatorial auctions (CAs) have been developed for numerous applications in transportation, including freight transport procurement in the trucking industry (Figliozzi et al., 2003; Caplice and Sheffi, 2003; Song and Regan, 2003; Song and Regan, 2004; Song and Regan, 2005; Sheffi,2004; Wang and Xia, 2005; Krajewska and Kopfer, 2006; Guo et al., 2006; Lee et al., 2007; Ergun et al., 2007a,b; Chang, 2008), and aircraft arrival/departure slot allocation (Ball et al., 2006; Cramton, 2006). These works consider auctions of sets of individual lanes and arrival/departure time slots at transport terminals. Such techniques while relevant cannot be applied in the context of track capacity allocation in rail operations.

In the context of rail transport, a few works (Affuso, 2003; Gibson, 2003; Newbery, 2003; Perennes, 2013) have debated the feasibility of distributing rail track access rights to carriers through the use of auctions. They suggest the replacement of traditional administrative processes for allocating track capacities by an auction framework to establish more transparent and fair access to rail network capacities. They provide some insights on how to utilize the auction process for this purpose.

Brewer and Plott (1996) proposed a game-theoretic approach to address the freight train scheduling problem. A binary conflict ascending price mechanism, a decentralized mechanism based on a first-price auction, was proposed. Through numerical experiments, it was shown that this mechanism can be used for capacity allocation. In their experiments, ten study participants represented