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Capacity allocation in vertically integrated rail systems: A bargaining approach

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ABSTRACT

This paper presents a game-theoretic bargaining approach to allocating rail line capacity in vertically integrated systems. A passenger rail agency negotiates with the host freight railroad to determine train schedules and the associated payment. The objective on the passenger side is to maximize utility, i.e., revenue minus costs of passenger train operations, passenger schedule delay and en-route delay; the freight side minimizes the costs of train departure delay, en-route delay, loss of demand, and track maintenance. Bargaining in both complete and incomplete information settings are considered; the latter arises because the freight railroad may withhold its private cost information. With complete information, we find that the equilibrium payments proposed by the passenger rail agency and the host freight railroad will each be invariant to who initiates the payment bargaining, although the actual payment does depend on who is the initiator. The equilibrium schedule maximizes system welfare. With incomplete information, the passenger rail agency may choose between pooling and separating equilibrium strategies while proposing a payment, depending on its prior belief about the cost type of the freight railroad; whereas the host freight railroad will adopt strategies that do not reveal its cost type. To identify equilibrium schedules, a pooling equilibrium is constructed along with conditions for the existence of equilibrium schedules. We further conduct numerical experiments to obtain additional policy-relevant insights.

1. Introduction

Rail is an essential component in the US passenger and freight transportation system. On the freight side, rail transports about 27% of total freight revenue ton-miles (US DOT, 2012), with Class I railroads' revenue ton-miles increased from 1495 billion in 2001 to 1729 billion in 2011 (AAR, 2012). On the passenger side, Amtrak, the national intercity transportation service provider, has set ten ridership records over the last 11 years, carrying more than 31.5 million passengers in 2013 (Amtrak, 2013). Amtrak's operation is characterized by the shared use of infrastructure with freight railroads, as 70% of Amtrak's train miles are produced on tracks which are owned and maintained by host freight railroads (Amtrak, 2012). The flourishing of passenger rail has spurred the development of Higher Speed Rail (HrSR) services (FRA, 2015), which still run

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on shared-use tracks but at a higher speed, up to 110 mph (Peterman et al., 2009). Compared to conventional Amtrak trains, introducing HrSR means greater speed heterogeneity between passenger and freight operations, which has negative impact on the rail line capacity (Talebian and Zou, 2015). Given the HrSR development and the expected continuous growth of freight and passenger rail traffic, having appropriate mechanisms in place has become increasingly critical to efficiently and fairly allocate capacity between passenger and freight operations on shared-use rail lines.

One premise for allocating rail line capacity is to understand capacity. Two aspects are of particular importance. First, the capacity of a rail line depends on how conflict-free train schedules are created; thus capacity is endogenously rather than exogenously determined (Pena-Alcaraz et al., 2014). Second, the consequence of increasing rail service by one operator may not only delay trains on the line, but can also lead to the inability of other operator(s) to schedule as many trains as they originally demand (Talebian and Zou, 2015). The latter is termed capacity scarcity (Nash and Matthews, 2003; Nash and Sansom, 1999). Capacity scarcity is especially relevant when one type of trains is scheduled before another type. In the US, Amtrak services are given higher access priority over freight operations by Public Law (110 Congress, 2008).

In addition to the above two aspects, appropriate mechanisms for rail line capacity allocation hinges on how a rail system is structured – more specifically, whether infrastructure ownership and train operations are vertically integrated or separated. The US rail system has long been vertically integrated, with majority of the rail tracks owned by freight railroads, on the ground that such system takes advantage of economies of scale which minimize train operating expenses; in contrast, separation of infrastructure ownership from operations would require effective communication between different entities which may elevate costs. While there are concerns about vertically integrated systems for the lack of competition, the counterargument is that sufficient competition already exists – from alternative modes, different transportation sources, and between adjacent lines (Drew, 2009). Among the empirical investigations, Bitzan (2003) finds that the cost of resource use would increase if the US rail system were to be vertically separated; a different view is provided by Ivaldi and Mc Cullough (2001), who argue that there may be no inherent advantages of vertical integration. Although debates on whether vertical separation is needed in the US rail system will continue, for the foreseeable future the existing vertical integration structure is likely to remain unchanged.

The state-of-the-practice allocation of rail line capacity between a host freight railroad and Amtrak is primarily conducted through negotiation based on Public Law 110-432 (110 Congress, 2008). In general, the negotiation process, which is due to the legislated power being not absolute, consists of determining passenger train schedules and payment between Amtrak and freight host railroads for track usage and penalty for train delays (US DOT, 2010). The negotiation process is extensively covered in the industry press (e.g., in magazines like Railway Age and Trains) and well known to those who follow North American railroads, although published formal disclosure is limited. The academic literature on negotiation-based capacity allocation in vertically integrated systems is also quite scarce – if it exists – which is in sharp contrast with the abundant knowledge on how to allocate capacity in vertically separated systems (see Section 2 below).

The present paper makes the first attempt to fill this gap. We propose a game-theoretic bargaining approach to modeling capacity allocation on a vertically integrated rail line. A mathematical structure generally consistent with the practice is established to characterize how passenger and freight sides bargain to determine train schedules and payment from the passenger rail agency to the host freight railroad. We incorporate a range of cost components that are also in line with the practice. We further recognize that the passenger rail agency may not possess full cost information about the host freight railroad, and extend the bargaining model from a complete to an incomplete information setting. Through analytical solutions and numerical analysis, we obtain a number of policy-relevant insights, which advance the knowledge and help inform future practices on capacity allocation on vertically integrated, shared-use rail lines in the US.

The modeling framework developed in this paper could be of potential use in other contexts as well. One example is the Chinese High-Speed Rail (CHSR) system where the passenger rail operator, which owns and operates CHSR, negotiates with the dedicated freight HSR operator for line capacity allocation. The issue of capacity allocation will likely become more important given the growing use of high speed rail for intercity logistics as driven by the rapid development of e-commerce in China. Another example is vessel chartering in maritime transportation, where a charterer negotiates with a ship owner on shipping price, volume, and time. More generally, the game-theoretic bargaining framework developed in this paper could be applied to a range of transportation settings where negotiation and/or contracting is involved, such as between shippers and carriers in the trucking industry and in aircraft leasing. The framework may be used to investigate other domains as well including pipelines and electric power grids – basically any time a government seeks to break up a monopoly or provide a product or service which the commercial market has refused to provide.

The remainder of the paper is organized as follows. Section 2 presents a review of existing mechanisms for rail line capacity allocation, based on which the contributions of the present study are highlighted. Section 3 puts forward the modeling framework, ensued by a description of the pre-bargaining input preparation in Section 4. The bargaining model is presented in Section 5. Section 6 offers numerical analysis and results discussions. Summary of major findings and directions for further research are given in Section 7.

2. Literature review and contributions of the present study

Mechanisms for rail line capacity allocation can be broadly categorized into three groups: administrative, value-based, and market-based. Administrative mechanisms employ a set of rules, such as “intercity trains go first” (Gibson, 2003), to allocate train paths to operators. Such mechanisms do not rely on values for rail infrastructure capacity, and are mostly em-