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Itinerary choice and advance ticket booking for high-speed-railway network services

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ABSTRACT

This paper formulates and examines the passenger flow assignment (itinerary choice) problem in high-speed railway (HSR) systems with multiple-class users and multiple-class seats, given the train schedules and time-varying travel demand. In particular, we take into account advance booking cost of travelers in the itinerary choice problem. Rather than a direct approach to model advance booking cost with an explicit cost function, we consider advance booking cost endogenously, which is determined as a part of the passenger choice equilibrium. We show that this equilibrium problem can be formulated as a linear programming (LP) model based on a three-dimension network representation of time, space, and seat class. At the equilibrium solution, a set of Lagrange multipliers for the LP model are obtained, which are associated with the rigid in-train passenger capacity constraints (limited numbers of seats). We found that the sum of the Lagrange multipliers along a path in the three-dimension network reflects the advance booking cost of tickets (due to advance/early booking to guarantee availability) perceived by the passengers. Numerical examples are presented to demonstrate and illustrate the proposed model for the passenger assignment problem.

1. Introduction

In recent years, the high-speed railway (HSR) systems are being developed rapidly worldwide to connect major cities, including cross-border HSR network in Europe (e.g., Eurostar connecting United Kingdom, France, and other countries), and country-wide networks in, e.g., China, Japan. Particularly, China has the world's longest HSR network with over 19,000 km of track in service as of January 2016, and a network length of 38,000 km is planned for 2025 (Railway Gazetter, 2016). High-speed trains can cover relatively long distances in short times and thus save travel times of passengers significantly. This inevitably results in high and increasing passenger demand for HSR systems, especially in countries such as China with a very dense population. Therefore, passengers often need to book a train ticket sufficiently in advance to guarantee availability. This advance/early booking can create additional inconvenience and/or cost to passengers, which affects passengers' itinerary choices. Characterized by the rigid seat capacity constraints and the required advance ticket booking/purchase, the emerging HSR networks in China and other countries ask for a new challenging passenger flow assignment model to capture how ticket-booking cost (associated with advance/early booking)

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could reshape the passenger flows in the HSR networks. This is distinguished from the conventional public transit traffic assignment models that have been well studied in the literature where advance booking is not very relevant.

More specifically speaking, for HSR systems, travelers usually book the tickets in advance through the internet or smartphone apps (e.g., www.12306.com in China; www.eurostar.com in Europe; www.virgintrains.co.uk in UK), or purchase the tickets at ticket offices in a pre-sale period. The key and most innovative aspect for HSR passenger assignment under our concern is that, due to rigid seat capacity constraints[1], individual travelers may not be able to obtain their desirable train service with respect to departure time, route and seat class, depending on how early they make their ticket booking. This "early-booking" to ensure ticket availability indeed can yield non-negligible cost to travelers, which is defined as the advance booking cost. For instance, Hetrakul and Cirillo (2013, 2014) pointed out that the utility of passenger booking the tickets should include the cost of booking-in-advance, which can be proportional to the number of days between the booking day and departure date. Ongprasert (2006) argued that the advance ticket booking cost also includes the penalty for the risk of ticket cancellation. It is obvious that these studies treated advance booking cost from an individual perspective. However, it is worth mentioning that how individual evaluates the inconvenience/cost due to early or advance booking will involve private information and situations (e.g., activity schedule flexibility; uncertainty of future activities and travel plan).

Unlike the airline industry where air tickets are sold at different prices in different presale time, which greatly affects passenger's choice of airline itinerary and fare product (Carrier, 2008), HSR ticket price is usually more flat (e.g., in China the price is the same for different booking times).[2] This means that HSR passengers' decision of ticket-booking time is mainly governed by factors such as uncertainty of travel plan prior to departure other than ticket fare variation. However, the advance booking (or early booking) cost is often not directly observable from a system operator's or planner's point of view due to the two facts (as mentioned earlier): (i) it involves private information/hidden action of travelers, and (ii) many different factors jointly affect individual passenger's perceived cost or valuation of advance booking (e.g., activity schedule flexibility; uncertainty of future activities and travel plan) even the ticket fare or price is fixed over the booking period (as in the case of Chinese HSR). In this study, the advance booking cost is endogenously treated and determined as the outcome of the passenger choice equilibrium. It reflects how much the passengers are "willing-to-pay" (for advance booking) to secure a ticket for the preferred trains (with ideal departure and arrival times, and shorter journey times, etc.). This is further explained by the following example with a single origin-destination pair and two trains.

Suppose we have two trains to serve one origin-destination pair. Let us consider that the direct cost components are the travel time, train fare, and schedule penalty (due to deviation from ideal departure time). For simplicity, the travel times and fares for the two trains are identical (e.g., 3 h and 300HKD). The departure times are 9:00 am and 11:00 am and the train capacities are 600 and 1800 for the first and second trains, respectively. The total demand is 2000 ($600 < 2000 < 600 + 1800$), and let us simply adopt homogeneous users with a desired departure time of 9:00am, i.e., we assume that all passengers want to depart at 9:00am. It is evident that all the travelers prefer to take the first train and it saves a direct cost of 60HKD = 30 HKD/h × (11:00 am – 9:00 am = 2 h) if we assume that the schedule penalty is 30 HKD/h. However, travelers have to book the ticket of the first train in advance to secure a ticket (the demand 2000 is much larger than the capacity of the first train 600). The "60HKD" reflects how much the passengers are "willing-to-pay" for early booking or how early they are willing to book a ticket. For example, if the early-booking could cost the passengers 15HKD/day (i.e., it costs 15HKD by forwarding the booking time by one day), travelers will book a ticket for the first train 4 days in advance ($4 = 60/15$). Note that the "60HKD" here is inferred from the difference in the direct cost components for the two trains. If one takes an explicit approach to model the advance booking, one may have to, e.g., specify the booking time of the passengers and the early-booking penalty per unit time (day). Differently, this paper takes a choice equilibrium approach to capture the advance booking cost. In this example, 600 users should take train 1 and the other 1400 will take train 2. For the 600 users taking train 1, their advance booking cost (due to booking tickets early) is equal to the schedule penalty for (11:00 am – 9:00 am = 2 h), i.e., 60HKD. Later, we will show that the 60HKD is related to the Lagrange multiplier associated with the rigid capacity constraint of train 1 in a passenger assignment model. We do not need to explicitly consider the exact booking behavior (e.g., booking time, penalty for unit time of advance-booking) in order to determine the advance booking cost. With such an endogenous consideration of advance booking cost, the system reaches an equilibrium at which all travelers have the same total individual travel cost (direct cost + advance booking cost).

The proposed approach offers some advantages in the sense that it avoids modeling such exact booking behavior (over calendar time), which, as mentioned earlier, involves private information of "willing-to-pay" for travelers that is quite often not directly observable or measurable. More specifically speaking, each individual may evaluate advance-booking differently. If we model the advance-booking cost with an explicit function for advance booking (regarding booking time, travel plan uncertainty, activity

[1] This paper considers that passengers have expected information regarding the capacities and availability of trains. Also, they have expectations about how much time in advance they have to book tickets for certain trains. This might come from their own travel experience or experience shared by others. This might also be provided by train service operators given the fast-growing smart technologies. For real-time or nearly real-time train capacity and availability information, one may find them on websites such as 12306.cn (for China), or partial information on websites such as www.eurostar.com and the official site for Virgin Train (UK). Moreover, in future mobility-as-a-service systems (e.g., automated vehicle/train systems), the mentioned information is expected to be available to passengers and advance booking might be required for mobility services. The developed methodologies in this paper in principle can be extended to these automated and booking-required mobility systems, such as the reservation/booking system for highway use proposed by Liu et al. (2015).

[2] The train ticket fares in some countries may vary with the booking time over the sale horizon (e.g., Hetrakul and Cirillo, 2013), which is under our consideration for future research (e.g., examine how to optimally set the fares that could improve efficiency of flow patterns in the HSR networks).