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A hierarchical line planning approach for a large-scale high speed rail network: The China case

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ABSTRACT

Planning a set of train lines in a large-scale high speed rail (HSR) network is typically influenced by issues of longer travel distance, high transport demand, track capacity constraints, and a non-periodic timetable. In this paper, we describe an integrated hierarchical approach to determine line plans by defining the stations and trains according to two classes. Based on a bi-level programming model, heuristics are developed for two consecutive stages corresponding to each classification. The approach determines day-period based train line frequencies as well as a combination of various stopping patterns for a mix of fast trunk line services between major stations and a variety of slower body lines that offer service to intermediate stations, so as to satisfy the predicted passenger transport demand. Efficiencies of the line plans described herein concern passenger travel times, train capacity occupancy, and the number of transfers. Moreover, our heuristics allow for combining many additional conflicting demand–supply factors to design a line plan with predominantly cost-oriented and/or customer-oriented objectives. A range of scenarios are developed to generate three line plans for a real-world example of the HSR network in China using a decision support system. The performance of potential train schedules is evaluated to further examine the feasibility of the obtained line plans through graphical timetables.

1. Introduction

Over the past six-year period, China has newly built the largest high speed rail (HSR) network in the world, with lines in operation amounting to 11,132 km. The rapidly growing China HSR network is already larger than the combined HSR networks of 13 European countries (7351 km) and accounts for nearly 48 percent of all HSR lines in the world (UIC, 2014). By 2020, 192 cities of prefectural-level with about 783 stations will be connected by HSR lines. In many cities, more than one station on the network is necessary due to very high passenger volume. Passenger travel will be facilitated between metropolitan areas, and a wide service is extended to a number of small cities. Fig. 1 describes the backbone of the entire HSR network that will consist of 4 vertical lines and 4 horizontal lines with the major cities presented. China has chosen to build most of its HSR lines exclusively for passenger services. The alignment of new lines is basically parallel to conventional rail lines aiming at solving capacity restrictions and congestion. However, HSR lines in densely populated corridors

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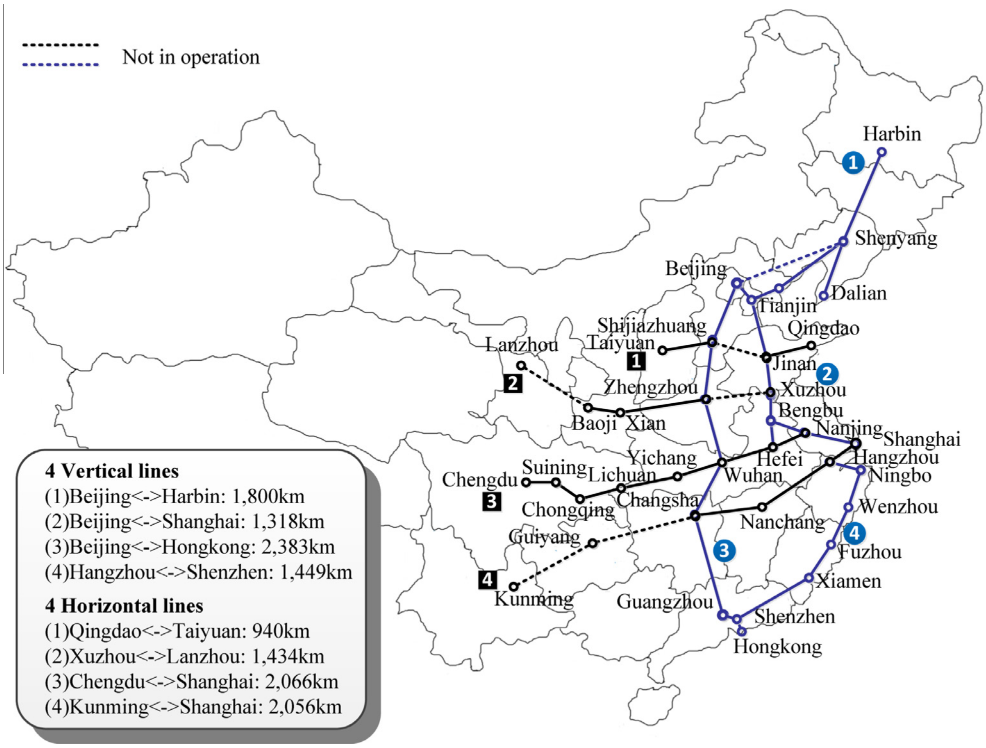

Fig. 1. Planned HSR network in China. *Source:* Fu et al. (2012), UIC (2014).

still suffer capacity shortage during peak seasons, which is partly attributable to a limited daily operating period of 18 h, because currently 6 h are used for maintenance during night.

Typical large-scale HSR lines in China are different from standard medium-scale HSR lines like in Japan and Europe due to their very long distance of more than 1000 km between the terminal stations. A number of long-distance trains are operated even though people do not always travel from one end terminal to the other end of a line. The average passenger travel distance on two main lines, for example, Beijing–Guangzhou HSR (2281 km) and Beijing–Shanghai HSR (1318 km) are about 558 km and 621 km, respectively. The purpose of operating such long-distance trains is mainly to serve as many travelers as possible directly between origins and destinations (ODs); otherwise, people would need to transfer, which is inconvenient for most due to heavy luggage. This purpose further needs to be assured by providing intermediate train stops, where suitable, in order to restrict the number of train OD sets.

The station density of the HSR lines varies by different ODs. For example, there are 43 stations (average station spacing 52 km) on the Beijing–Guangzhou HSR and 23 stations (average station spacing 60 km) on the Beijing–Shanghai HSR. Moreover, China has a balanced regional structure but uneven passenger traffic distribution, the population of cities with stations on the Beijing–Shanghai HSR, for example, varies from 3.14 million (Zhenjiang city) to 23.64 million (Shanghai city) (China City Statistical Yearbook, 2012). On the one hand, technically, trains dwelling at frequent stops significantly reduce the mean operating speed, yet not every station has sufficient overtaking tracks to allow train overtaking due to speed differential. On the other hand, economically, there is a need for better assigning the train frequencies at stations according to the passenger transport flows to ensure satisfactory train occupancy rates. Therefore, the planning of the different train lines and service frequencies of the stations in the HSR network must be determined such that the train line capacity meets the passenger demand, and the passenger travel speed over long distances is high, while the track and station capacity is used efficiently. The "line plan" specifies the routes between origin and destination stations, subsequent stops at intermediate stations and the corresponding train capacity and frequency.

The line planning problem (LPP) for the HSR network in China is different from other smaller countries, such as Japan or in Europe, because of the larger size of the network, the very high transport demand, longer travel distance, track capacity constraints, and non-periodic timetable. In practice, since HSR lines in China are gradually put into operation, first the train lines between selected stations on a single HSR line are determined, and then the train lines merging and diverging to/from stations of interconnected HSR lines are inserted. In the past the individual train lines and timetable were manually designed, while the total network performance was investigated only ex post.

In this paper, we present an integrated hierarchical line planning approach for the generation of the train stopping pattern, frequency, and scheduling of mixed passenger lines on large-scale HSR routes. As the current daily operating period