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# Integrated multi-track station layout design and train scheduling models on railway corridors

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ABSTRACT

The dwelling capacity of the station (mainly determined by its multi-track layout) is a practically significant factor to influence the quality of the train schedules, especially in a busy railway corridor with heterogeneous trains and complex operations. To improve the passing capacity and transportation efficiency, this paper focuses on a network design problem over a railway corridor, in which some critical stations are considered to enlarge the number of siding tracks or platforms within the budget constraints. To evaluate the quality of design strategies, the construction cost and total travel time in the corresponding optimal train schedule are adopted as evaluation indexes. Based on two specific modeling methodologies, two types of optimization models are particularly formulated with different considerations. One is a single-level linear mixed-integer programming (S-LMIP) model based on the space–time network representation method; the other is a bi-level programming model associated with the platform choice-based method, where the upper level of the proposed model aims to design new siding tracks/platforms in the candidate stations, and the lower level is a train scheduling model with assigning the tracks for each train at each station. The commercial software GAMS with CPLEX solver and local searching based heuristic with integrated CPLEX solver are respectively employed to solve the near-optimal solutions for these two types of models. Finally, two sets of examples, in which a sample railway corridor and the Wuhan–Guangzhou high-speed railway corridor are adopted as the experimental environments, are implemented to illustrate the performance and effectiveness of the proposed approaches.



## 1. Introduction

Due to the advantages of the large capacity, high security and high capability of resistance to bad weathers, the railway transportation system, especially the high-speed railways, has tremendous growth in recent years in order to meet the rapid increase of passenger and freight transportation demands. To enhance the utilization efficiency of the current infrastructure, railway companies and train dispatchers are often faced with high-requirements in railway planning optimizations. In general, the railway planning problem can be decomposed into a succession of sub-problems due to the complexity of railway systems, such as line planning, train timetabling, train platforming/routing, rolling stock circulation, train unit shunting and crew scheduling (Huisman et al., 2005; Cacchiani et al., 2006; Lusby et al., 2011). As pointed by Cacchiani et al. (2006), these

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sub-problems of the railway planning optimization are typically not independent and choices taken to solve one of these sub-problems might heavily influence others.

The train timetabling problem, which is the most important part among the aforementioned sub-problems of railway operations, aims to specify the departure and arrival times of each train at each station with a series of operational constraints. In reality, to carry out operations according to the optimized timetable, many safety conditions should be further guaranteed, especially for dwelling operations at each station. With the pre-specified timetable, the train platforming problem aims to find an assignment plan of trains to platforms when they enter, dwell at and depart from a railway station (Caprara et al., 2011). In this problem, the multi-track station layout (i.e., the numbers of platforms/siding tracks of the station) must be known before the platforming process. Since the dwelling capacity of each station is mainly dependent on the layout of siding tracks, in the following discussion, the description of dwelling capacity is supposed to be related to the multi-track station layout. Note that, the dwelling capacity of each station specifies the maximum number of trains that can occupy the station simultaneously, and the timetable determines the time intervals of individual trains' occupancies. In this sense, the dwelling capacity of each station has great influence on the generated timetables over the railway corridor. For instance, in the process of train platforming, the generated timetable might be further adjusted to meet the practical operation conditions if only a small number of trains are allowed to occupy some stations at the same time. Additionally, although the dwelling capacity constraints can also be considered in the timetabling process to generate a non-adjustment timetable in the viewpoint of train platforming, appropriately enlarging the dwelling capacity of some critical stations can still lead to a large ratio of total travel time reductions (see Section 2 for more details). Due to the complicated environments, however, the construction cost of enlarging the dwelling capacity is often restricted by a lot of factors, e.g., the geographical positions, the number of service lines of the station, etc., leading to different costs for enlarging the dwelling capacities of various stations. Besides, the maximum potential dwelling capacity of each station is also practically distinctive. Thus, how to reasonably design multi-track station layout to optimize dwelling capacity is a theoretically significant issue for improving the current railway infrastructure.

Aiming to produce an optimal multi-track station layout design plan and the corresponding optimal timetable with various requirements, we are especially interested in making a balance between the total construction cost and the total travel time reduction of the generated timetables from the viewpoint of academic studies. Since this topic has still not attracted sufficient attention in the literature, this research will formally address this problem.

### 1.1. Literature review

The train timetable essentially specifies trip times of individual trains in the transport process of the railway traffic system, which has a substantial influence on the transportation efficiency and customers satisfaction. Due to its indispensable significance in practice, this problem has attracted tremendous attention from a variety of engineers and researchers over the past decades. In the literature, as classified by Cacchiani et al. (2006, 2008) and Barrena et al. (2014), two types of versions with respect to this problem have been extensively studied, i.e., the cyclic/periodic timetabling and noncyclic/nonperiodic timetabling.

The cyclic timetable usually decomposes all trains into a series of groups with the same number of trains, where only one group of trains (usually a small-scale model) need to be optimized and then this timetable is repeated with a fixed time interval for other groups of trains. As a result, the cyclic timetable is in general much easier to handle for the railway companies since the following processes of railway optimization also can be seen as a cyclic process, such as rolling stock planning and crew planning (Peeters, 2003). In the literature, since Serafini and Ukovich (1989) first proposed a new formulation for periodic scheduling in 1989, termed as the periodic event scheduling problem (PESP), a lot of researchers studied the cyclic timetabling problem on the basis of this formulation, such as Odijk (1996), Kroon and Peeters (2003), Peeters (2003), Lindner and Zimmermann (2005) and Liebchen (2008). Specifically, by considering the arrival and departure times being related pairwise on a clock, rather than on a linear time axis, Odijk (1996) formulated a mathematical model consisting of periodic time window constraints for periodic timetable and proposed a new algorithm based on a constraint generation algorithm. Kroon and Peeters (2003) provided an extension model for the PESP by including the variable trip times. Lindner and Zimmermann (2005) formulated a mixed integer linear programming model for the cyclic scheduling problem to minimize operational cost of train schedules by considering choosing different train types with diverse speed and cost. In addition, considering that the timetable is always disturbed by various disturbances, Kroon et al. (2008) proposed a stochastic optimization variant of the PESP to allocate the time supplements and buffer times to the timetable so as to improve the robustness of generated timetables.

Nevertheless, as pointed out by Peeters (2003), Cacchiani et al. (2006) and Caprara et al. (2007), the cyclic timetable is usually much expensive to operate since even in period of a day where a few trains are needed one must execute the same timetable used in the peak hours. With this concern, a lot of researchers turn their attention to address the noncyclic timetabling problems which have a relatively pleasurable performance on meeting the variations of passenger demands and some other complexity situations. For the noncyclic timetabling problem, Szpigel (1973) first formulated it as a mixed integer programming and solved small instances of the problem by using branch and bound algorithm. Higgins et al. (1996) presented a two-objective optimization model on single-track railway corridor to minimize the total delay and fuel consumption cost. Zhou and Zhong (2007) proposed a generalized resource-constrained project scheduling formulation on a single-track rail corridor, and presented a branch-and-bound solution procedure to obtain feasible schedules with