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A train rescheduling model integrating speed management during disruptions of high-speed traffic under a quasi-moving block system

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A B S T R A C T

Chinese high-speed railways faced a fast development in recent years. Their performances are still confronted with disruptions unavoidably, which impact on the reliability of the traffic and passenger satisfaction. This paper presents a rescheduling model which is able to solve the critical problem of effective disruption management (namely, fast and dynamic train speed adaptation, supervision of braking and changing train sequence due to incidents, warnings or alarms), and consider in detail the signalling and safety systems based on a quasi-moving block system with variable headways. We integrate the modelling of efficient traffic management measures and the supervision of speed, braking and headway in one general job-shop model. We use a commercial solver with a custom-designed two-step method to speed up the procedure in order to solve instances from real-world high-speed networks in China quickly. Overall, the approach guarantees the resolution of the traffic control and speed management within few minutes of computation time. The output demonstrates that the proposed approach can achieve a reduction of train delays by 70% compared to the solution determined by keeping the order of the original timetable, and get the optimality for more than 90% of instances with a realistic case.

1. Introduction

The development of high-speed railways in China has been fast and impressive. In recent 10 years (2007–2017), more than 20,000 km of high-speed rail track have been made available, which are utilized by more than 4,200 high-speed trains per day. The service is being recognized as very attractive to passengers due to the short travel time and the high speed, which may even exceed 300 km/h. However, this system is not immune to delays and disruptions caused by some inevitable events, alarms, or technical failures. Some of those effects can result in temporary interruptions of operations (see Zhan et al., 2015) or more commonly, conflicts, primary delays, or speed restrictions of trains. These generate knock-on delays and further disturbances, which reduce the benefit of high-speed trains, result in longer travel time and degrade operations reliability. These incidents decrease greatly the satisfaction and travel comfort of the passengers, and ask for increased workload of the dispatchers to adjust the railway traffic during operations.

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As mentioned in Zhan et al. (2015), the operating rules of high-speed trains are different than those of conventional speed trains, and require new approaches, in order to integrate the safety-critical elements of the operating rules. In fact, operating speeds above 200 km/h require continuously updated accurate distance headway between consecutive trains according to advanced signalling and safety systems such as moving blocks, other than the traditional 3-aspects fixed-block signalling systems, and moreover more prompt adjustment in the case of abnormal situation. This often involves dynamic train speed reductions and fast dispatching measures like changing train orders or running times. Dispatchers of high-speed railway lines are challenged to update tight train schedules and solve disruptions under strong time pressure.

Real-time rescheduling of railway traffic (which we call traffic management or traffic control) has gained an increasing recognition in recent years due to the development and deployment of intelligent traffic management systems, but there are still very few approaches, which can properly model the dynamics of high-speed railway lines. In fact, there is currently no real-time rescheduling model that can optimize the train operations with the quasi-moving block signalling system of the Chinese high-speed railway lines in the case of disruptions.

However, a prompt and reliable decision support for dispatchers in the case of disruptions requires the integration of a real-time rescheduling model at a microscopic scale and at the same time a highly accurate real-time train speed management. Furthermore, the majority of research on microscopic real-time rescheduling are confronted with small primary delays, and avoid large scale adjustments corresponding to disruptions, strong speed limitations, and blockages. Finally, among the literature dealing with disruptions, the most common situation considered is a black/white blockage, while a more realistic situation is a gray-area of speed reduction due to warnings or degraded operating conditions. Implementing speed reduction policies is crucial to keep safety and traffic going to avoid a full blockage, but reduces the transport capacity; conversely, travel times of trains will increase for a given period of time. When this is combined with the possibility of small random delays, the need to quantitatively support human dispatchers by quick and effective traffic control is evident. We therefore address the real-time problem of rescheduling high-speed railway services to reduce delays, under a quasi-moving block safety system, when the trains are disturbed by delays and disruptions affecting the operating speed. This complements the macroscopic optimization model proposed by Zhan et al. (2015) which focused on full blockages and neglected some operational principles affecting microscopic operations and speed of trains.

More precisely, the key contributions of our approach are:

1. A job-shop scheduling model on a microscopic scale is presented, describing the existing quasi-moving block signalling system in China by means of alternative graph formulation;
2. The model integrates one single optimization process with two separate decisions, i.e., traffic management (orders and times) and train control (speed management), which were typically dealt with in a decomposed, iterative or non-optimized manner in previous research;
3. The model is used for solving disruptions, which affect the operating speed of trains for a variable time and geographic extension, with a given start and end time within the optimization horizon and represent the most common issues on Chinese high-speed lines, and concurrent shorter delays perturbing further the traffic;
4. A two-step procedure is proposed to speed up the computation of upper and lower bounds, which enables a considerable improvement compared to using a commercial solver;
5. We test our model on the Wuhan-Guangzhou high-speed railway line with different degrees of speed limitation and a realistic set of primary delays;
6. A comprehensive analysis of two different operating plans (with homogeneous/heterogeneous speed traffic) identifies the potential improvement compared to several typical benchmark strategies;
7. The model can be used as decision support for train dispatching to improve the performance of high-speed railway operations in China and elsewhere.

The remainder of the paper is organized as follows. Section 2 presents a comprehensive literature review on railway real-time rescheduling, for disturbances/disruptions, and with/without consideration of train speed. In Section 3, we explain the problem, the features of the quasi-moving block signalling and safety system, and describe the typical disruptions faced. Then, a mixed integer linear programming model is formulated in Section 4. Section 5 reports the main computational experiments. A summary of conclusions and recommendations for future research is closing the paper in Section 6.

2. Literature review

The possibility to reschedule railway traffic to reduce impact of delays and disruptions has been attracting much attention in recent years. We here go quickly through the available scientific literature, clustering together mathematical optimization approaches which focus on the general problems of normal speed railway traffic; those that focus on disruption management; and those that include explicitly speed modelling and management in their analysis. We direct for more information to the recent surveys in Cacchiani et al. (2014), Corman and Meng (2014) and Fang et al. (2015).

2.1. General delay management

Several approaches based on operations research techniques are widely used to update a timetable when small delays occur, by producing a disposition schedule. This latter is the product of control actions such as retiming (change passing