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Operational risk analysis of block sections in the railway network

Weiting Zhao, Ullrich Martin*, Yong Cui, Jiajian Liang

Institut für Eisenbahn- und Verkehrswesen, Universität Stuttgart, Pfaffenwaldring 7, 70569 Stuttgart, Germany

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ABSTRACT

The scheduling of railway networks is becoming more vulnerable to operational disturbances due to increasing traffic demand and limited infrastructure expansion. This leads to severe outcomes including the breaking of the connection between adjacent trains, deterioration of the service levels for customers, and even the collapse of the entire railway operation. Therefore, it is important to design a railway system that is highly-resistant against operational disturbances. For both robust timetabling and dynamic dispatching based approaches, identifying critical railway block sections is always the prerequisite. This study conducts an operational risk analysis by developing an "operational risk index" (RI) based on statistical methods and railway simulation tools. In the proposed algorithm, random disturbances are firstly artificially imposed on a target block section and the influences (RI) on the entire railway network are then calculated to evaluate the operational risk of this target block section. A case study is conducted on a reference railway network. Results indicate that the algorithm proposed within is capable of thoroughly evaluating the operational risk level of block sections and is also compatible with different distribution types of random disturbances, applicable to different traffic volumes (condensed timetables), and stable among basic timetables with slight adjustments of freight transport schedules.

1. Introduction

vRailway systems contain various endogenous and exogenous disturbances that may lead the train operation to deviate from the basic schedule. Due to increasing traffic demand and limited infrastructure expansion, the schedules of current railway networks are highly susceptible to even small operational disturbances. Disturbances may result in breaks in the connections between adjacent trains, deterioration in the service levels for customers and in the worst case, the entire railway operation may break down. Therefore, it is important to design a railway system that is highly resistant to operational disturbances. Nowadays, inevitable operational disturbances are handled simultaneously in two major ways: robust train timetabling at the primary planning stage and synchronous dispatching in the case of occurrence of conflicts in real time operation. On one hand, a majority of studies that focus on robust timetable construction have been conducted by setting

* Corresponding author.
E-mail addresses: weiting.zhao@ievvwi.uni-stuttgart.de (W. Zhao), ullrich.martin@ievvwi.uni-stuttgart.de (U. Martin), yong.cui@ievvwi.uni-stuttgart.de (Y. Cui), jiajian.liang@ievvwi.uni-stuttgart.de (J. Liang).

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buffer time[1] and recovery time[2] in the basic timetable[3] (Huisman et al., 2007; Kroon et al., 2008; Shafia et al., 2012; Andersson et al., 2013; Lindfeldt, 2015), so as to neutralize the disturbances and keep them from spreading across the network. On the other hand, a growing stream of dispatching algorithms have been developed for solving the conflicts caused by operational disturbances within a deterministic framework, in which conflicts are not able to be neutralized by recovery time and buffer time set in the basic timetable (Cheng, 1998; Bidot et al., 2006; Nash and Ullius, 2004; D'Ariano, 2008; Espinosa-Aranda and García-Ródenas, 2012; Quaglietta et al., 2013). Under all circumstances, the identification of critical block sections, which are vulnerable to the operational disturbances and will more likely break down the railway operation, is the prerequisite for both of the two methods mentioned above. On the basis of block section vulnerability, it is possible to improve timetabling through optimally setting limited time reserves (recovery time and buffer time) (Martin, 2014) on different block sections that vary with their vulnerability. By setting extra time reserves for vulnerable block sections and less time reserves for non-vulnerable block sections, primary delays as well as consecutive delays can be avoided without the degradation of railway network capacity. On the other hand, the vulnerability of block sections also plays a significant role for conducting more robust dispatching. In the phase of conflict detection, the artificially prolonged blocking time on vulnerable block sections can provide a precise estimation in advance, so as to enable the implementation of dispatching solutions in a timely manner.

Studies on identifying the critical block sections in railway systems are also known as “bottleneck analysis”. At the moment, there is no consensus on the definition of bottlenecks, with different parties adopting various interpretation of the phenomenon. A bottleneck is defined as “the decisive network element for the capacity performance, whose utilization rate lies in the deficient range of the quality” in (DB NETZ AG, 2008). While the International Union of Railway (*UIC*) identifies a bottleneck section of a railway network as a very highly utilized network element (UIC, 2013). Based on an analytical approach, a detailed consideration of the utilization rate, including investigations of infrastructure and rolling stock characteristics, timetable scheduling, and other related properties was conducted in order to identify the bottlenecks. From the point of view of a simulative approach, Hantsch et al. (2013) developed a new definition of bottlenecks as infrastructure sections which may severely affect other train paths and the railway operation on adjacent sections, as well as lead to adverse effects on operating quality. Among the various definitions, different bottleneck analyses are conducted, accordingly. Hartwig (2013) suggested that bottleneck analysis rely on the analysis of transport infrastructure, transportation model of demand prediction, and the average waiting time of existing timetable and conditions of the railway facilities. Drewello and Günther (2012) proposed a bottleneck analysis that ranges beyond solely capacity discussion and includes the economical, spatial, and social contexts. Pöhle and Feil (2016) applied shadow prices of a developed column generation method as the indicator for identification of bottlenecks, which evaluated bottlenecks in terms of monetary units. Li and Martin (2015) applied three indicators including bottleneck sensitivity, unfulfillable occupancy requirements, and occupancy rate to locate the bottleneck sections from operational perspectives. Additionally, bottleneck significance and bottleneck relevance were initially developed to differentiate a given bottleneck in the condition of a concrete traffic volume (bottleneck significance) and a potential bottleneck that appears when the traffic volume increases (bottleneck relevance) (Martin and Li, 2015). Rotoli et al. (2016a; 2016b) proposed a synthetic methodology for the capacity and utilization analysis of complex interconnected railway networks based on a schematization of typical components (stations and line's segments). This approach had specific advantages mainly in the joint analysis of nodes and lines, which allowed for the identification of bottlenecks from all the elements of the network. It included certain additional and consistent assumptions, and is particularly useful in the case of feasibility studies in which detailed data are not available.

However, there is quite limited research on bottleneck analyses based on the vulnerability of infrastructure sections. Andersson et al. (2013) discussed some disturbance-sensitive locations as critical points in the process of quantitative robustness analysis, and those points were identified simply through empirical observations of the Swedish timetable and traffic in 2011. Instead of critical points, the disturbance-sensitive block sections are identified as bottlenecks in this study. The vulnerability of block sections, which refers to the susceptibility to disturbances that can result in considerable reductions in railway network serviceability, is reflected by the indicator “operational risk index”. It is the expected value of the negative impacts caused by the occurrence of disturbances on the specific block section. Different from the indicators (i.e., bottleneck sensitivity, unfulfillable occupancy requirements, occupancy rate) developed in (Martin and Li, 2015) which focus on the hindrance on the operation of other trains caused by the occupancy of the infrastructure sections, the indicator “operational risk index” concentrates on the overall impacts caused by operational disturbances occurred on certain block sections. It provides a forewarning for the severe impacts that may possibly be caused by disturbances. Therefore, the results of the analysis can serve as the foundation for developing an innovative dynamic dispatching algorithm with consideration of potential random disturbances. Furthermore, it can be also applied for effective timetabling at the primary stage, ranking the construction projects related to infrastructure expansion or maintenance and capacity research of the railway network.

This study attempts to explore the negative impacts on the entire railway network caused by disturbances on each single specific block section instead of focusing on the varying utilization rates of each block section in real time operation. On the

[1] Buffer time: an extra time which is added to the minimum line headway to avoid the transmission of small delays (Pachl (2002)).

[2] Recovery time: a time supplement that is added to the pure running time to enable a train make up small delays (Pachl (2002)).

[3] Basic timetable: it includes a set of information with detailed train plans, defining several months in advance the train order and timing at crossings, junctions and platforms.

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