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A delay root cause discovery and timetable adjustment model for enhancing the punctuality of railway services ☆

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ABSTRACT

Knock-on delay, which is the key factor in punctuality of railway service, is mainly related to two factors including the quality of timetable in the planning phase and disturbances which may result in unscheduled trains' waiting or meeting in operation phase. If the delay root cause and the interactions among the factors responsible for these can be clearly clarified, then the punctuality of railway operations can be enhanced by taking reactions such as timetable adjustment, rescheduling or rerouting of railway traffic in case of disturbances. These delay reasons can be used to predict the lengths of railway disruptions and effective reactions can be applied in disruption management. In this work, a delay root cause discovery model is proposed, which integrates heterogeneous railway operation data sources to reconstruct the details of the railway operations. A supervised decision tree method following the machine learning and data mining techniques is designed to estimate the key factors in knock-on delays. It discovers the root cause delay factor by logically analyzing the scheduled or un-scheduled trains meetings and overtaking behaviors, and the subsequent delay propagations. Experiment results show that the proposed decision tree can predict the delay reason with the accuracy of 83%, and it can be further enhance to 90% if the delay cause is only considered "prolonged passengers boarding" and "meeting or overtaking" factors. The delay root cause can be discovered by the proposed model, verified by frequency filtering in operation records, and resolved by the adjustment of timetable which is an important reference for the next timetable rescheduling. The results of this study can be applied to railway operation decision support and disruption management, especially with regard to timetable rescheduling, trains resequencing or rerouting, system reliability analysis, and service quality improvements.

1. Introduction

Railway systems, with the features of mass transit and green transit, serve as the transportation backbones in many countries. Timetable is very important in rail planning and operation since it defines how the various resources are integrated and managed, including the crews, rolling stocks, and infrastructure facilities. Timetable plays a key role in integration of operations and planning in railway systems. For railway systems with published timetables, punctuality is an important measure of reliability and service quality (Yuan, 2006), both in the view of the railway operators and travelers. However, punctuality

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may be affected by several factors, including weather, the capabilities of the rolling stock, driver behavior, traveler behaviors (prolonged passengers boarding and alighting at stations), and even the quality of timetables (Wu, 2012), which determines how well capacity is utilized and how stable the operations are (Sameni et al., 2011). It is unavoidable that the operation of a railway system encounters unexpected disturbances and disruptions which result in infeasibilities in the timetable (Cacchiani et al., 2014; Zilko et al., 2016). Due to interruptions or disturbances with regard to the electricity supply, wind, humidity, driver behaviors, mechanical conditions, and so on, delays are often inevitable in real railway operations. Among the various delay factors, timetable is the most economic control factor, and the quality of a timetable is related to the punctuality of a railway system.

A timetable explicitly specifies the track assignment of every train services at every stations the service passes (enter and exit time), and has to comply with all physical restrictions and operation regulations, most of which can be expressed as the minimum headway between trains, the maximum/minimum amount of time a service is allowed to occupy a block, and the physical fact that every train in the system has to occupy some space on the track at any time (Chen et al., 2013). To meet operational requirements and ensure safety, several scheduled activities, such as overtaking, waiting, and meet-and-pass, are defined in timetable to specify where and when multiple trains should behave within the stations. For example, an unscheduled train overtaking by another priority train that is given preferential treatment can result in increased delays and may deteriorate the punctuality.

Interactions between two trains in a railway system can be classified as "meeting", "overtaking", and "waiting". "Meeting" is when two trains cross (meet) each other at a station, which is the core feature of single-track operation. "Overtaking" indicates that a priority train takes over slower ones by using the related facilities, and "waiting" means a train waiting other trains to meet (when moving in the opposite direction) or overtake (when moving in the same direction) at stations. Fig. 1 shows several interactions of the four train services (Train I–Train IV). For example, Train I is scheduled to meet (cross) with Train III at station B and overtake Train IV at station C on a single-track system, however, it has to wait if Train III is delayed, and this delay will propagate to the overtaking (Train IV waiting) at station C. Similarly, if the scheduled service by which Train II overtakes Train I at station A is delayed, the delay will propagate to all the subsequent train services, including the opposite direction services (Train III).

Passenger demand forecasting handbook (Association of Train Operating Companies (ATOC), 2005) distinguishes between delay and lateness, in which "delay is used to refer to the difference between the actual and working times to pass over short route sections" and "lateness refers to the difference between the actual and public timetable arrivals at destination stations", and thus a delay can be calculated by the difference between a train's actual arrival time and its scheduled arrival time of each stop in the timetable. Scheduled delays are mainly caused by the timetable assignment to avoid conflicts and ensure safety, with low priority trains usually scheduled to wait for high priority trains meeting (using the same track) or overtaking at stations. A knock-on delay (i.e., delay propagation), which are usually caused by route conflicts, prolonged alighting and boarding times of passengers, and other exogenous delays to railway operations, may significantly affect global punctuality, as the delay to one train may propagate to other trains (Hwang and Liu, 2010). Goverde (2005) defined the primary delay of a railway system as "the deviation from a scheduled process time caused by disruption within the process", and a secondary delay as "the deviation of a scheduled process time caused by conflicting train paths or waiting for delayed trains". In other words, a secondary delay is propagated by a primary delay, and one train's delay may propagate to other trains and result in delay chaining, which will reduce overall punctuality. For example, a delayed train may propagate the delay to the subsequent trains using the same track, and delayed meeting or overtaking events may even propagate the delay to the opposite direction and its subsequent train services. According to Chen (2010) and Wu (2012), the reasons for delays can be classified into four categories: station-related, train-related, operation-related, and timetable-related, as illustrated in Table 1.

Cordeau et al. (1998) presented a comprehensive survey on optimization model of train scheduling and routing problems. Törnquist (2006) reviewed the models and algorithms for railway scheduling and dispatching for decision support. Study in Hansen (2010) discussed the railway timetabling and dynamic traffic management, a real-time traffic optimization model was proposed for rescheduling or rerouting of railway traffic in case of disturbances. Meng and Zhou (2011) developed a robust train dispatching model with a multi-layered branching procedure which systematically generate a series of

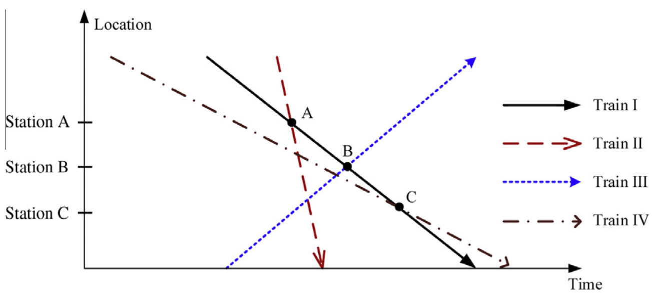

Fig. 1. Train diagram for descripting the train interaction behaviors.