Increasing performance of railway systems by exploitation of the relationship between capacity and operation quality

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Abstract
In this research, the influence of dispatching on the relationship between capacity and operation quality was evaluated systematically, so that real-time operation-oriented dispatching and long-term planning-oriented capacity research can be connected. The advantages are: on one hand, suitable dispatching algorithms can increase the capacity while meeting certain operation quality requirements; on the other hand, the accuracy of capacity research can be improved. Both of them are required to increase the infrastructure exploitation rate and avoid redundant infrastructure investments. In order to evaluate these influences, the dispatching algorithm was clearly defined in advance. A state-dependent dispatching optimization algorithm was developed based on greedy algorithm. The state-dependent variable in the optimization algorithm could be adjusted in each system state in order to achieve the best performance of the algorithm. The system state is characterized by three attributes in this article: the traffic flow, the average waiting time per train and the proportion of the delayed trains covering the whole investigation area. This article presents an innovative approach for the optimization of dispatching algorithms as function of the system state, in order to evaluate its impact on capacity and operation quality by means of microscopic simulation.

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1. Introduction

Capacity research is applied to describe the relationship between capacity and operation quality within a defined investigated area of a certain infrastructure network. When simulation methods are used in capacity research, the integrated dispatching modules will influence the final results of capacity research. In the simulation of disturbed timetables with stochastic deviations, dispatching modules will be called on to solve or avoid conflicts when conflicts occur or when potential conflicts are detected. The relationship between capacity and operation quality, which is represented by the results of capacity research, include the maximum capacity, the recommended areas of traffic flow and the waiting time function (Hertel, 1992; Pachl, 2002). These all will be different depending on the employment of different dispatching algorithms in reality and simulation of railway operation respectively. In the worst case scenario with a large number of trains, an unsuitable dispatching algorithm perhaps cannot realize the timetabled capacity, which underlines the importance of choosing suitable dispatching algorithms for the target capacity. In this research, capacity research was carried out with simulation method, and
the influences of the dispatching algorithms on the relationship between capacity and operation quality was compared and summarized. This article is the first attempt to evaluate the structurized influences of dispatching on the relationship between capacity and operation quality based on the theory of capacity research of railway systems. The structure of this article is organized as follows: the related literature will be summarized in Section 2; the state-dependent dispatching algorithm developed in this research will be briefly introduced in Section 3; the details of the system state classification will be elaborated in Section 4; based on the state-dependent dispatching algorithm and system state classification, the influence of dispatching on the relationship between capacity and operation quality will be systematically evaluated in Section 5; eventually, the conclusion of this research will be presented in Section 6.

2. Literature review

In order to evaluate the influences of dispatching on the results of capacity research, railway operation processes should be simulated with a large quantity of system conditions with stochastic deviations. In different system conditions, the dispatching algorithms may have to be modified correspondingly to fulfill a pre-defined objective function. In Horng (2006) it is shown that the selection of the best dispatching rule is affected by the system utilization rate in flow shop, job shop, and open shop problems. In Vepsalainen (1984), state dependent priority rules for scheduling, in flow shop and job shop problems are comprehensively investigated, and the scope and detail of the system state information is classified into three categories: local, indirect global, and direct global information. In Moulahi-Chibani and Pierreval (2010), system state is characterized through a series of system parameters, and a neutral network is used to describe the mapping relationship between dispatching priority rules and system states in flexible manufacturing systems. Similarly, system states should also be considered in the rescheduling processes of railway operations, which have been rarely studied in existing research. One simple example is shown in Martin (1995): trains have the same priority in case of congestion, and have different priorities in case of normal dispatching conditions. Another example is shown in Oetting (2010), on single-track sections if the occupation rates exceed a threshold value, trains with the same direction will be bundled in the case of deviations. In this project, the system states will also be classified according to the number of trains per hour, the average knock-on delay and the proportion of delayed trains over the studied network within a certain time interval.

To generate a large amount of timetables with stochastic deviations that contains different system states, the software PULEIV which has been developed by IEV (Institut für Eisenbahn und Verkehrswesen der Universität Stuttgart) (Martin and Schmidt, 2010) can be used. Within the PULEIV generated timetables, initial delays of trains at the boundary of the investigation areas and original delays of trains at their origin stations located within the investigation areas are modelled by negative exponential distribution.

In the design of dispatching algorithms, generally three types of dispatching approaches could be considered: simulative, analytical and heuristic approach (similar classification also can be found in Corman and Meng, 2013, Martin, 2002 and Cui, 2010). With the simulative approach the operation process is simulated as in reality. During the simulation process, traffic situations are predicted periodically. Once a conflict is detected, the integrated dispatching module will be called on to solve the conflict, and the processing technique of the simulation model (i.e. synchronous and asynchronous) plays an important role in the mechanism of conflict resolution. For synchronous simulations, train movements are updated progressively and interacting with each other immediately (Siefer, 2008). Therefore, the integrated dispatching module imitates dispatchers to solve conflicts chronologically. For instance, a series of dispatching measures, which include overtaking, replatforming, dwell time extension and so on, are implemented in the software RailSys (RMCon, 2007). When potential conflicts are detected during the simulation process, suitable dispatching measures will be performed. For asynchronous simulations, train paths are inserted in the time-distance diagram in sequence of priority. A dispatching assistant tool — ASDIS (Asynchronous Dispatching) — was developed in the research project DisKon (Schaer et al., 2005). After a train group (with the same priority) was inserted, the conflicts among the equal or higher-ranking trains should be resolved chronologically.

With analytical approaches, train operations are modelled as mathematical equations, such as mixed integer linear programming (Corman et al., 2017), queuing theory (e.g. Marinov and Viegas, 2011) and alternative graph model (e.g. Corman et al., 2011 and D’Ariano and Pranzo, 2008) and so on. For overviews of mathematical models we refer to Alwadood et al. (2012), Cacchiani et al. (2013) and Corman and Meng (2013). It is very complex and time-consuming to solve the analytical models with exact method. The heuristic approach is a good alternative, which can balance the solution quality and computation time.

Heuristic approaches include a wide range of algorithms, such as tabu search, simulated annealing, swarm intelligence and so on. In Cui (2010) a macroscopic railway dispatching optimization model was developed based on tabu search, in which changes of train sequences on open track sections are defined as basic move operations. In D’Ariano (2008) tabu search is used to optimize train paths, and the Branch and Bound algorithm to optimize the train sequences on infrastructure resources. Samà et al. (2016) chose the ant colony (an example of swarm intelligence) as the basis of the dispatching optimization algorithm, and aimed to solve the train routing selection problem. Many heuristic or metaheuristic algorithms are available to be used as the basis of the dispatching algorithm in railway operation. A widely used heuristic algorithm — greedy algorithm — was preferred in this research. The local search mechanism of the greedy algorithm is the basis of many heuristic and metaheuristic algorithms. Therefore, the specific local search mechanism developed in this section can be easily implemented under the framework of other heuristic or metaheuristic algorithms.
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