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Non-discriminatory train dispatching in a rail transport market with multiple competing and collaborative train operating companies

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A R T I C L E I N F O

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A B S T R A C T

Train dispatching is vital for the punctuality of train services, which is critical for a train operating company (TOC) to maintain its competitiveness. Due to the introduction of competition in the railway transport market, the issue of discrimination is attracting more and more attention. This paper focuses on delivering non-discriminatory train dispatching solutions while multiple TOCs are competing in a rail transport market, and investigating impacting factors of the inequity of train dispatching solutions. A mixed integer linear programming (MILP) model is first proposed, in which the inequity of competitors (i.e., trains and TOCs) is formalized by a set of constraints. In order to provide a more flexible framework, a model is further reformulated where the inequity of competitors is formalized as the maximum individual deviation of competitors' delay cost from average delay cost in the objective function. Complex infrastructure capacity constraints are considered and modelled through a big *M*-based approach. The proposed models are solved by a standard MILP solver. A set of comprehensive experiments is conducted on a real-world dataset adapted from the Dutch railway network to test the efficiency, effectiveness, and applicability of the proposed models, as well as determine the trade-off between train delays and delay equity.

1. Introduction

Providing punctual and reliable services is a main goal of train operating companies (TOCs) in order to maintain and further improve their competitiveness in the rapidly changing multimodal ***transport market***. As tactical plans, train timetables are typically computed offline, months before operations to specify a physical network route and detailed arrival and departure times at passing stations for each train. While a planned train timetable is put into operation, unavoidable stochastic perturbations (e.g., bad weather, extra passenger flow, and capacity breakdowns) may influence the scheduled train running and dwelling times, thus causing primary delays to normal train operations. Due to the high interdependency between trains for the available capacity, primary delays may further result in snowball effect on other trains with consecutive delays in a rail network. The key task of train dispatching is to take proper measures which can recover the impacted schedules from

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perturbations and further reduce potential negative consequences. Ineffective train dispatching could significantly downgrade the punctuality of train services and the overall system performance.

Railways have developed as vertically-integrated (state-owned) organizations, which have been the most common structure for the rail sector in most countries, with responsibility for both the railway infrastructure facilities and train operations (Kurosaki, 2008). Since the 1990s, rail policy regulations in Europe have fostered competition into the rail transport market. This led to a vertical separation between infrastructure management and train operations, the progressive opening up to the market for new operating companies, and the rules regarding the allocation of slots and the pricing of infrastructure use, administered by an independent regulator (Nash and Rivera-Trujillo, 2004). Directive 91/440/EC (Commission of the European Communities, 1991) is one of such policies, which forced separation of concerns in the railway transport field, by specifying the roles of Infrastructure Manager (IM) and Railway Undertakings (RUs) or Train Operating Companies (TOCs). The former is in charge of making infrastructure available for both tactical train timetabling and operational train dispatching, and the latter has economic interests to strive for increasing ridership. Such policies consider competition among TOCs as a key element to achieve efficient operations. Nevertheless, situations of quasi-monopoly are common, which may result in discriminatory treatment among different TOCs, in both tactical train timetabling and operational train dispatching. Similar situations exist in China, where passenger trains are generally put in a high priority in using tracks than freight trains. This is a rather standard allocation approach, but it seriously affects the interests of freight TOCs and downgrade the efficiency of the whole system, particularly during perturbations. To protect the legitimate rights and interests of TOCs and keep an orderly market, providing non-discriminatory access to rail infrastructure for TOCs is of great importance, in both planning and operational control levels.

The competitive interaction, concerning equity among multiple TOCs, has been studied so far mostly from a policy and financing point of view. Those are offline issues addressed during design and strategic planning, including for instance the equitable allocation of timetable slots. As requested in Directive 2001/14/EC (Commission of the European Communities, 2001), the access to the rail infrastructure for all TOCs should be provided in a fair and non-discriminatory manner. This requirement is reflected in the timetable planning process, which follows a sequence of applications of TOCs for infrastructure capacity, scheduling the requested applications, coordination of the conflicting requests, (if conflicts still exist, then) declaring the infrastructure congested, and employing non-discriminatory priority criteria to allocate the congested infrastructure. However, the rules for access and use of the infrastructure during real-time traffic management mainly focus on restoring the normal situation and do not require a special focus on non-discriminatory actions. Additionally, penalties may be charged for the actions that disrupt the normal operation, compensation may be granted for the TOC which suffer from disruption, and TOCs may be rewarded for better than planned performance. During online operations, the available capacity can be reduced by delays and delay propagation, which may result in infeasibility of the planned train timetables. TOCs only look at maximizing their interests and suffer from negative effects of delays, leading to passenger dissatisfaction, refund, and penalties. The problem we have is then how to allocate this (reduced) capacity among competing TOCs without favoring any of them, i.e., how to provide non-discriminatory access to the limited capacity for the competing TOCs. In fact, few online (i.e., in relation with real operations) approaches are known to address this problem. Most existing studies on train dispatching focus on minimizing the negative impacts of perturbations and pay little attention to discrimination (which corresponds to delay inequity) among competing TOCs while generating dispatching solutions (see the review paper by Cacchiani et al., 2014). This brings about the motivation of this paper, i.e., delivering non-discriminatory train dispatching solutions in order to protect the rights and interests of TOCs during real-time train dispatching, and filling the research gap in the literature.

In this paper, we focus on generating non-discriminatory train dispatching solutions (or achieving an acceptable degree of equity while dispatching), and exploring the aspects related to delay equity. We address the problem of dispatching trains in a non-discriminatory way: this means that we use an optimization approach to explicitly consider delay equity among multiple competing TOCs or trains, in addition to minimizing average (consecutive) train delay time. We consider delay equity as the degree of homogeneity of the delays faced by different trains, or trains of different TOCs. An inequitable (or discriminatory) situation occurs when some trains or some TOCs, face much larger delays than other trains or TOCs.

The remainder of this paper is organized as follows. Section 2 provides a detailed literature review on relevant studies, e.g., network access and competition policies, equitable capacity allocation in train timetabling, real-time train dispatching without considering delay equity, and equitable traffic control in other transport modes. In Section 3, mathematical models are proposed, including a model (P1) representing equity in constraints, a model (P2) representing equity in objective function, a model (P3) without considering equity as a benchmark, and a model (P4) considering consecutive delay equity only. Section 4 presents a detailed description of experimental settings, followed by the analyses of the experimental results in Section 5, which quantify the trade-off between train delays and delay equity and the key determinants of delay equity. Finally, conclusions and suggestions for further research are given in Section 6.

2. Literature review

This section presents a detailed review on relevant policies and scientific studies. We first investigate the policies concerning network access and competition in the railway transport field in Section 2.1, followed by discussing the studies on the equitable capacity allocation (offline train timetabling) in Section 2.2. Then, in Section 2.3, we review the studies