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Closing the loop in real-time railway control: Framework design and impacts on operations

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ABSTRACT

Railway traffic is heavily affected by disturbances and/or disruptions, which are often cause of delays and low performance of train services. The impact and the propagation of such delays can be mitigated by relying on automatic tools for rescheduling traffic in real-time. These tools predict future track conflict based on current train information and provide suitable control measures (e.g. reordering, retiming and/or rerouting) by using advanced mathematical models. A growing literature is available on these tools, but their effects on real operations are blurry and not yet well known, due to the very scarce implementation of such systems in practice.

In this paper we widen the knowledge on how automatic real-time rescheduling tools can influence train performance when interfaced with railway operations. To this purpose we build up a novel traffic control framework that couples the state-of-the art automatic rescheduling tool ROMA, with the realistic railway traffic simulation environment EGTRAIN, used as a surrogate of the real field. At regular times ROMA is fed with current traffic information measured from the field (i.e. EGTRAIN) in order to predict possible conflicts and compute (sub) optimal control measures that minimize the max consecutive delay on the network. We test the impact of the traffic control framework based on different types of interaction (i.e. open loop, multiple open loop, closed loop) between the rescheduling tool and the simulation environment as well as different combinations of parameter values (such as the rescheduling interval and prediction horizon). The influence of different traffic prediction models (assuming e.g. aggressive versus conservative driving behaviour) is also investigated together with the effects on traffic due to control delays of the dispatcher in implementing the control measures computed by the rescheduling tool.

Results obtained for the Dutch railway corridor Utrecht–Den Bosch show that a closed loop interaction outperforms both the multiple open loop and the open loop approaches, especially with large control delays and limited information on train entrance delays and dwell times. A slow rescheduling frequency and a large prediction horizon improve the quality of the control measure. A limited control delay and a conservative prediction of train speed help filtering out uncertain traffic dynamics thereby increasing the effectiveness of the implemented measures.

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1. Introduction

Railway traffic is expected to solve many mobility problems such as reducing road congestion and car emissions in cities and densely populated areas. Anyway, train services are often subject to delays, which affect both the comfort and the travel time of passengers. This limits the attractiveness of railways against private cars and inhibits reaching the target of modal share set by international policies. In fact, due to high frequency train services and limited infrastructure upgrades, railway networks are very sensitive to delay propagation (Goverde, 2010). Unavoidable statistical fluctuations of train running and dwell times propagate around the network as knock-on delays in a snowball effect, affecting widely traffic and passengers. Lately, optimized timetables have been developed, that, based on mathematical programming approaches, define movements of trains which deliver better services to passengers and absorb minor delays by smartly interconnecting services and distributing time reserves (Dewilde et al., 2014; Kroon et al., 2009).

Nevertheless, no optimized timetable can be made resistant against all kind of possible disturbances (Hansen and Pachl, 2008; Kauppi et al., 2006). To limit the propagation of delays, and to recover possibly infeasible or conflicting train movements, it is necessary to update the original timetable according to the current status of the network. This means to define ad-hoc control measures that based on current traffic information produce a new conflict-free train path plan (a train path plan is a collection of control actions, resulting in a disposition timetable). Typical control measures include reordering trains at switches and platforms, shifting train paths in time (retiming) and/or changing the route of trains at stations or along the tracks. Mostly these are taken on the basis of rules-of-thumb and/or the personal experience of the dispatchers who have only a limited knowledge of downstream traffic (Kauppi et al., 2006). Moreover, the complexity of controlling railway traffic might not be humanly manageable when large railway networks, heavy perturbations and/or dense traffic areas are considered. Because of such reasons, control measures decided by human dispatchers can be ineffective or even counterproductive in some cases.

To this end, automated real-time railway traffic control systems have been proposed and their application in practice seems to be imminent (Harrod, 2011). These systems automatically compute suitable control measures on the basis of the current measured state of railway traffic and the prediction of its future evolution. They provide the dispatcher with updated train service schedules that minimize (from a mathematical point of view) delays and/or other measures of performance. Local rules, heuristics or mathematical programming approaches are used for this purpose. So far, research has investigated the possibility of defining advanced mathematical programming models with the assumption that the quality of the actions computed by the automatic rescheduling tools would directly translate in a similar quality for the real situation of running traffic. The weakest points of such assumption relate to the fact that relevant aspects of the interaction with the real field are not considered, like: (i) stochastic external disturbances to real train operations (e.g. unforeseen dwell and/or running times extensions), (ii) missing or erroneous information about current traffic state, (iii) dynamic changes of the traffic information needed for rescheduling, (iv) delay in communicating the computed control measures to real traffic (i.e. control delay). The main open question for both researchers and practitioners is whether automatic rescheduling tools can concretely reach the improvements found in theory, when instead they are actually interfaced with real-life operations.

The interaction between the rescheduling tool and traffic operations can follow different schemes, that we call control schemes. In particular we distinguish amongst an open loop, a multiple open loop and a closed loop control scheme. In an open loop, the control actions are computed and implemented only once at the beginning of a control period (i.e. the time period during which the traffic is controlled), assuming that the traffic states over the entire period are perfectly known. A wide literature deals with this kind of rescheduling such as (Albrecht et al., 2006; Boccia et al., 2013; Corman et al., 2009, 2014; D'Ariano et al., 2007; Harrod, 2011, 2012; Jacobs, 2004; Meng and Zhou, 2011, 2014; Pellegrini et al., 2014; Törnquist Krasemann, 2012). The fact that the control action is applied only one time makes the open loop scheme unable to react to unpredictable changes to the traffic states when unplanned events occur over time. An open loop control can be therefore applied at successive times over the control period, leading to the concept of multiple open loop control. In such an approach, the control measures computed at a certain time do not consider the actions implemented at the previous time points. This simplification results in the fact that the multiple open loop does not consider memory of past traffic conditions nor of control measures previously implemented. In classic control theory, a closed loop system is the interaction between a (open loop) system and a controller, that checks and supervises the deviation of a variable from a target. In our terms, a key feature necessary to be able to track the deviation of a variable is the previous expectation of that variable, i.e. the memory of past values. We thus define a closed loop scheme as a multiple open loop with memory, repeatedly implementing control measures, computed each time on the basis of the current traffic state and the actions taken in the past.

The consequences on traffic performance due to the application of these systems in real networks are still un-investigated and unclear. Only a few prototypes of these tools have been put into operation (Mannino and Mascis, 2009; Mazzarello and Ottaviani, 2007) and analysis against railway traffic simulators are also very scarce (Larsen et al., 2013). This is one of the main reason why infrastructure managers are quite sceptic about the use of automated systems for optimal real-time railway traffic control.

In this paper we shed light on this issue by interfacing the tool for optimal railway rescheduling ROMA (see Corman et al., 2011) with the realistic traffic simulation environment EGTRAIN (Environment for the desiGn and simulaTion of RAIlway Networks) (Quaglietta and Punzo, 2013). We reproduce in the simulator typical phenomena of the real traffic control such