Combining Simulation and Optimization for Traffic Disturbance Recovery in a Busy Metro System

M. L. Tessitore\textsuperscript{a*}, M. Sam\textsuperscript{a}, A. D’Ariano\textsuperscript{a}, L. Hélouet\textsuperscript{b}, D. Pacciarelli\textsuperscript{a}

\textsuperscript{a}Roma Tre University, Department of Engineering, Via della Vasca Navale 79, 00146 Rome, Italy
\textsuperscript{b}Inria Rennes - Bretagne Atlantique Campus universitaire de Beaulieu Avenue du Général Leclerc, 35042 Rennes, France

The email of the corresponding author is: marta.tessitore@uniroma3.it

Abstract

This work studies the real-time train rescheduling problem for a busy metro system. The aim is to analyze how train delays propagate in the network due to small disturbances, while considering various types of recovery strategies. We compare optimization and rule-based algorithms and integrate them into the SIMSTORS traffic simulator. We use the heuristic and exact algorithms implemented in the AGLIBRARY solver. The resulting simulation-optimization framework is used to investigate the following operational issues: how to design suitable periodic or event-based strategies, how to setup the traffic prediction horizon dynamically, how to decide the frequency and the length of the optimization process. The proposed closed loop framework is used to evaluate several disturbance scenarios and simulation-optimization periods for a practical case study: the Santiago Metro Line 1, in Chile.

Keywords: Train Scheduling; Alternative Graph; Closed Loop System; Performance Assessment.

A safe, fast, and energy efficient metro system is one of the key elements for a sustainable urban transport system. However, due to the high frequency of services, metro networks are heavily affected by disturbances, or even disruptions, which make them particularly sensitive to delay propagation (Wang et al. 2018; Li et al., 2019; Huang et al., 2020). In the last years, Decision Support Systems (DSSs) are attracting the interest of practitioners to help train operators in the management of traffic disturbances. The general aim is to provide suitable control measures and achieve more punctual and reliable control strategies (Corman & Quaglietta, 2015; Quaglietta et al., 2016). Our work investigates the performance of various strategies for real-time train rescheduling in a busy metro system.

In the recent decades, the train rescheduling problem has received considerable attention. This problem consists of computing a schedule that minimizes the propagation of primary delays in order to recover from a degraded situation caused by a disruption. However, there is still a lack of practical implementations (several reasons are discussed in Liebchen & Schülldorf, 2019). Although several approaches have been studied, it is still very difficult to meet the required trade-off between the computational complexity and the desired quality of the solution. The use of traffic simulators and optimizers is very scarce, and their practical application is still not confirmed by practitioners (Borndörfer et al., 2017).

In busy metro systems, time is a key aspect during real-time rescheduling since the network status and forecast traffic conditions need to be constantly updated. A robust control feedback mechanism is thus required to get good performance during operations. We create a closed loop control framework that alternates the collection of updated data from the metro traffic simulator to the optimization of short-term traffic predictions. The aim of the work is to analyze how real-time rescheduling strategies can be implemented in a stochastic simulation environment. To perform this analysis, we consider a series of deterministic optimization scenarios, in which updated information is utilized to optimize short-term traffic predictions and to propose suitable train rescheduling actions.

SIMSTORS is the simulator of stochastic concurrent time events we use to represent trains’ movements at a mesoscopic level and to model stochastic disturbances of traffic flows (Adeline et al., 2017). SIMSTORS has been developed by the SUMO Team, at the INRIA Research Center in Rennes, France, during the joint ALSTOM-INRIA P22 Project. This simulator is based on a Stochastic Petri Nets variant and uses simple traffic regulation algorithms, working on local decision rules, to reschedule train departures and solve potential conflicts between trains at stations or along the lines.
AGLIBRARY is a deterministic solver for managing complex scheduling and routing problems, which has been recently applied to simulate and optimize train traffic flows of several conventional railway networks. This solver has been developed by the AUTORI Team, at the Engineering Department of Roma Tre University, Rome, Italy. AGLIBRARY formulates the real-time train rescheduling problem by means of the Alternative Graph (AG) formulation (D’Ariano et al., 2007), a generalization of the disjunctive graph for the job shop scheduling problem with no-store and no-wait constraints (Mascis & Pacciarelli, 2002). The train rescheduling problem is modeled via a set of nodes (operations), fixed arcs (operational constraints), and alternative arcs (train ordering decisions). This modeling structure allows efficient analysis of the feasibility (all constraints are satisfied) and quality (delayed trains) of a train rescheduling solution. Furthermore, efficient heuristic and exact algorithms based on AGs have been developed to compute efficiently near-optimal train scheduling solution (D’Ariano et al., 2007).

The coupling between SIMSTORS and AGLIBRARY is motivated by the need to find optimized recovery strategies for metro lines. We implemented various versions of the coupling, in which AGLIBRARY might suggest different traffic regulation strategies from train retiming to train reordering at some specific network points, such as the merging or turnaround points. The implementation of the coupling is based on the exploration of the following key parameters: how to design suitable periodic or event-based strategies, how to setup the traffic prediction horizon dynamically, how to decide the frequency and the length of the optimization process. The setting of these parameters might have a strong impact on the performance of the framework in terms of both solution quality and reliability.

The computational experiments proposed in this paper aims to investigate the recovery strategies and the parameters of the suggested closed loop architecture. We consider as a practical case study the Santiago Metro Line 1, in Chile, a bi-directional line with 27 stations and two intertwined rings where turnaround points are located both at central stations and at terminal ones. As, during a weekday, passengers demand is characterized by peak hours (in the morning, at lunch time and in the evening) and off-peak hours, the composition of train fleets is increased progressively to provide transport services during peak and then decreased. We consider both off-peak and peak hours plus several disturbance scenarios, ranging from light to large variations of running and dwell times.

Preliminary results on various settings of the closed loop framework show that the best performance, in terms of train delay minimization and system reliability, is achieved when using the optimization algorithms of the AGLIBRARY scheduler compared to the rule-based traffic regulation inspired by hold-on strategies, i.e. maximum adherence to the predetermined schedule.

References


