Transportation Research Part C 79 (2017) 73–84

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Rescheduling through stop-skipping in dense railway systems ☆

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ARTICLE INFO

Article history:
Received 29 April 2016
Received in revised form 17 March 2017
Accepted 18 March 2017

Keywords:
Rescheduling
Integer Linear programming
Macroscopic modelling
Real time
Dense railway system

ABSTRACT

Based on the analysis of the railway system in the Paris region in France, this paper presents a rescheduling problem in which stops on train lines can be skipped and services are retimed to recover when limited disturbances occur. Indeed, in such mass transit systems, minor disturbances tend to propagate and generate larger delays through the shared use of resources, if no action is quickly taken. An integrated Integer Linear Programming model is presented whose objective function minimizes both the recovery time and the waiting time of passengers. Additional criteria related to the weighted number of train stops that are skipped are included in the objective function. Rolling-stock constraints are also taken into account to propose a feasible plan. Computational experiments on real data are conducted to show the impact of rescheduling decisions depending on key parameters such as the duration of the disturbances and the minimal turning time between trains. The trade-off between the different criteria in the objective function is also illustrated and discussed.

1. Introduction and industrial context

About 18% of the French population live in the Paris region, which only covers 2% of the French territory. Every day, 8.3 million of trips are performed on the public transportation system in the Paris region. SNCF Transilien is a major operator of Paris suburban trains. Each day, Transilien must carry over 3.2 million commuters in 6200 trains on 1300 km of tracks. The number of passengers is continuously increasing (3% each year since 2000). To cope with this rise, trains have been added, up to 32 trains per hour run on the busiest parts of the infrastructure. Some lines are expected to reach a capacity crisis by 2020. Operating the Transilien rapid transit system is thus challenging on a daily basis. An unexpected large number of passengers boarding at a station or a minor technical problem can create small delays during running, dwell or turning times. These small delays are difficult to predict and, because of the saturation of the network, time buffers are not sufficient to absorb them. They can rapidly accumulate along lines and propagate to other delays, causing larger delays and degrading the quality of service offered to passengers.

Transilien combines the characteristics of regular trains and subways: (1) Tracks are shared with high-speed, regional and freight trains; drivers and rolling-stock are shared between Transilien lines; and several services (trains with different

☆ This article belongs to the Virtual Special Issue on "Integr Rail Optimization".

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http://dx.doi.org/10.1016/j.trc.2017.03.012

stopping pattern) exist on each line. Yet (2) the frequency is very high (less than 3 min on certain lines) and passengers connections do not need to be considered. Operational decisions like skipping a train stop or cancelling a whole train can thus be taken without severely impacting the quality of service, even though these decisions must be taken as early as possible to inform all operational actors and passengers.

Such decisions are sometimes hard to make because of the multiplicity and heterogeneity of actors involved in the Paris rapid transit system.

First, in agreement with the Paris transportation authority, Transilien takes into account precise performance criteria, for instance: The number of passengers delayed on each line and each branch and the number of trains actually operated compared to the number of trains planned. Other criteria concern the quality of service offered to passengers and the passenger information system, especially in case of disturbances. These criteria are associated with a bonus/penalty system associated to Transilien's performances. Secondly, the main goal of the infrastructure manager is that each train runs on time and respects its scheduled path. Thirdly, Transilien passengers expect frequent and rapid trains, they want comfortable trips with reliable service and information, whatever the train path, the rolling-stock unit or the driver.

In addition, many actors are involved in traffic management within Transilien, and have different objectives: Rolling-stock management, driver management, passenger information operators, etc. This makes the decision-making process complex and adds to the difficulty of implementing decisions.

Finally, Transilien operators need to find, at all times, the right balance between quality of service and performance. They need to constantly maintain a good quality of service for passengers and to fulfil the requirements of the transportation authority, while seeking performance, to minimize delays of trains, and to minimize costs. It is often hard to take real-time decisions that satisfy all the stakeholders simultaneously. For example, skipping stops on a delayed train may reduce the delay and avoid its propagation to the next train, but it affects the quality of service for passengers that wanted to board at the skipped stations and a penalty is incurred for delaying them. For most decisions, a trade-off has to be found between (1) penalizing a limited number of passengers and maybe paying a penalty or (2) risking to propagate the delay to the next train with potentially more passengers impacted and an even higher penalty to pay. Operators need to constantly have all criteria and constraints in mind to anticipate the potential impacts of each decision.

In real-time, Transilien operators need to quickly determine the best actions from a system-wide perspective. In this work, we develop a real-time integrated rescheduling model that proposes stops to be skipped and a new timetable for trains in order to minimize both delay propagation and the waiting time of passengers. Moreover, we include both train rescheduling and rolling-stock constraints as turning times tend to propagate delays very quickly in dense systems.

The next section gives an overview of existing operational policies and rescheduling models for railway operations, as well as various approaches for bus or metro traffic. Section 3 presents the problem characteristics and various assumptions. Section 4 introduces a mathematical model in which train stops can be skipped. Section 5 presents the Transilien system characteristics, numerical results on real data obtained with the model, and discusses how to manage multiples criteria in the objective function. Section 6 presents results with multiple initial delays, associated to industrial instances. Finally, conclusions and directions for future work are provided in Section 7.

2. Literature review

Real-time traffic management consists in supervising the traffic and adjusting timetable, rolling-stock and driver schedules to prevent and reduce delays caused by incidents. Incidents can be either small perturbations called disturbances, or larger perturbations, called disruptions (Cacchiani et al., 2014). In this paper, we focus on disturbances that cause delays of a few minutes.

In recent years, Cacchiani et al. (2014), Corman and Meng (2015) and Toletti et al. (2015) reviewed several approaches that have been developed to propose automatic actions for railway traffic management. Different problems are usually defined, coping with different aspects of railway traffic. Each problem considers specific actions to cope with incidents, and tries to optimize a specific type of objective.

The *train dispatching* problem, also referred to as train path rescheduling or conflict prediction and resolution, consists in adjusting a timetable that has become infeasible because of disturbances or disruptions (Hansen and Pachl, 2008). Train routes, orders, timetable or speeds can be modified in order to achieve a feasible timetable. The objective is to improve the performance of the railway system by minimizing train delays and recovering the original timetable. Meng and Zhou (2014) propose to minimize the total deviation time from the original timetable, while Samà et al. (2016) choose to minimize the total consecutive delays. However, some approaches consider a passenger-based objective: Sato et al. (2013) propose a rescheduling model including train reordering and retiming (adjustments of the timetable) that minimizes the inconvenience of passengers (waiting time, travelling time and number of transfers). Caimi et al. (2012) propose a dispatching model that reroutes and re-platforms (changes in the platform assignment) trains in complex station areas, and maximizes the passenger satisfaction (maintained connections, schedule all trains and delays). In our problem, the layout of tracks does not allow for overtaking, thus trains cannot be rerouted or reordered. Reservicing actions, that consist in modifying the traffic plan (adding or skipping stops, cancelling trains, short-turning trains) can be included in train dispatching approaches. Sato et al. (2013) modify the train type in order to make an express train stop at a station that it should not serve. Veelenturf et al. (2016) propose partial or whole cancellations of trains in addition to rerouting and retiming for handling