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Demand-dependent supply control on a linear metro line of the RATP network

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1. Extended Abstract

1.1. Problem statement

Urban population and mobility needs are rapidly growing while transportation infrastructures are constrained by both limited space and budget allocation. Demand is greater than supply which produces saturation phenomena. Congestion is a major issue impacting the performance of urban transit systems in many ways: operating costs, efficiency and quality of service to name just a few. Regarding rail transit, congestion phenomena are observed in both train and pedestrian traffic. At metro stations, train and pedestrian flows meet and interact with each other. Pedestrian arrivals are pulsed by train arrivals and, inversely, train departures may be delayed because of an excessive number of passengers boarding or/and alighting. The interaction mainly occurs at the platform level where the exchange between passengers is observed.

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The very important train and passenger flows cause that even small perturbations propagate very quickly through the network. Delayed trains become more and more delayed, causing a hole to the preceding train, whereas traffic jams up behind the affected service. Due to the delay, passengers accumulate on the upcoming platforms, which extends the dwell time of the service. As a consequence, the delay of the affected train is further increased – leading to an even more important passenger accumulation on the following platforms. These cascade effects can be observed regularly especially during peak hour on the RATP network, the operator of the public transportation network of Paris, France.

The problem describes illustrates, why mass transit public transportation systems are intrinsically instable. To stabilize the traffic and offer a reliable service to customers, these networks need an efficient traffic flow control.

1.2. Research objectives

A major problem in optimizing rail operations is the fact that train scheduling is performed off-line and there exist few possibilities for real-time adjustments. Real-time adjustments, if any, are mainly based on expert opinion and not on modeling procedures. Examples include train holding at stations or skipping of stops. Such adjustments are meant to alleviate a certain problem but do not assure system- or line-wide optimization. Nevertheless, train traffic control measures have implications both upstream and downstream along the line concerned. Traffic control algorithms for railways typically aim to get back to a pre-defined schedule as fast as possible. This can result, as in Farhi (2017), in from a passenger point of view, absurd control decisions like shorting of dwell time of a delayed service in order to re-stabilize traffic.

Recent developments in data science allow public transportation operators to realize a short-term estimation of public transportation demand. For example, smart card data of a public transportation network, external data, such as weather forecast, traffic conditions and passenger counting via platform cameras etc. are available to realize a short-term passenger demand prediction.

Consequently, an innovative real-time control has to be designed as a schedule-free traffic control with demand-dependent dwell and running times. This allows dwell times being adjusted depending on the actual passenger demand for passenger convenience while limiting the risk of perturbations. To avoid the creation of irregular train time-headways, running times have to be modeled dynamically, too.

Finally, passenger control at the local level (i.e. the station) may be efficient to avoid important perturbations on the dwell time due to an excessive number of boarding passengers. Perturbations on the dwell time cause delays propagating quickly through the rest of the line. For example, passengers could be retained and stocked at the concourse level in order to avoid congestion on the platform. To the best of our knowledge, real-time control passenger measures have never been implemented to rail transit systems.

1.3. Methodological approach

The traffic model presented here is a discrete event model. It is based on a previous work in Farhi (2017), where dwell and running times are not modeled dynamically but are supposed to respect lower bounds. A space discretization of the metro line into n segments is considered, shown in Figure 1.

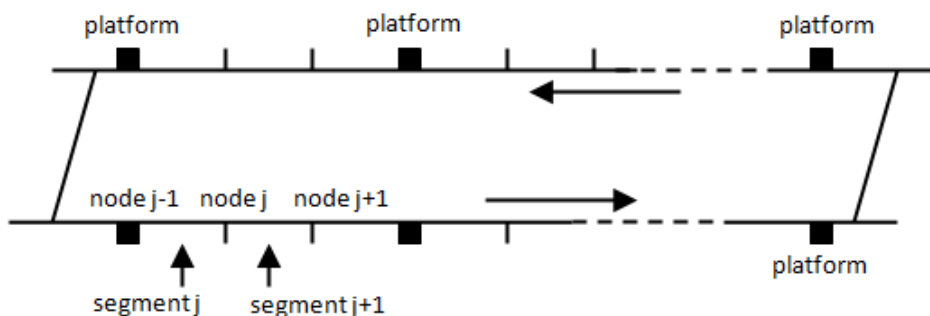


Figure 1: A linear metro line representation, discretized into n segments.

The notation used is accordingly to Farhi (2017). The main variable is the k^{th} departure time from segment j . Furthermore we note:

r_j	the running time of trains on segment j
$w_j^k = d_j^k - a_j^k$	the k^{th} dwell time on node j
$t_j^k = r_j + w_j^k$	the k^{th} travel time from node $j-1$ to node j
$g_j^k = a_j^k - d_j^{k-1}$	the k^{th} safe separation time at node j
$h_j^k = d_j^k - d_j^{k-1} = g_j^k + w_j^{k-1}$	the k^{th} departure time-headway at node j .

The model is based on two constraints. The travel time is the sum of running and dwell time for each segment. A safe separation time models the signaling system in case the traffic gets very dense. The safe separation time is the minimum time interval between the arrival of a train and the departure of the preceding one at the same segment j . The train dynamics are given by the maximum of the two constraints.

The main variables of interest are pedestrian flows, adherence to train time-headway/ frequency aims using train dwell and running times as proxy variables as well as the total number of trains moving on the line.

In this paper, we develop a model linking passenger volumes and stocks to train dwell, running times and train time-headway/ frequency. We implement the following levels of control:

First of all, for low passenger volumes, we optimize (i.e. shorten) station dwell time if it allows to realize a higher frequency. Inversely, under excessive passenger demand, we extend the dwell time for passenger convenience and control the number of trains to achieve traffic frequency objectives.

And secondly, for high demand, the access of passengers to the platforms is controlled to help respecting dwell times.

And finally, the traffic model also includes a running time control law. The running time control cancels perturbations on the dwell time so that delays do not propagate through the network.

1.4. Results

The discrete event traffic model is applied to a linear, automated metro line of the RATP network, the French capital's public transportation operator. The Automatic Train Operation, GOA 4, implemented on the RATP metro line, allows train dwell and running times to be controlled efficiently. We use three data sets for this case study:

First, smart card validation data to estimate passenger entries at each station aggregated over a 15 min-period.

Moreover, boarding/ alighting passengers statistics based on manual counting and inquiries of passengers on the platform.

And third, infrastructure parameters of the metro line such as the maximum speed for each segment, the nominal running times, the safe separation time and the nominal dwell times.

This paper presents an efficient control strategy for the number of trains, the dwell times, which satisfy the demand of boarding/ alighting passengers, and the running times to limit delay propagation through the network in order to realize the train time-headway/ frequency objectives.

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