PREDICTIVE TRAFFIC REGULATION ALGORITHM FOR A RAILWAY MASS TRANSIT LINE EQUIPPED WITH CBTC

Álvaro Cidoncha, Adrián Fernández-Rodríguez, Asunción P. Cucala, Antonio Fernández-Cardador

ABSTRACT

The main objective of the paper is the development of a twin model of a metro line for the testing and analysis of train traffic regulation strategies. In particular, a traffic regulator with continuous communication has been developed, based on the CBTC operation, which is capable of maintaining a regular interval and correcting deviations in commercial speed.

The mathematical model of the regulator is a predictive optimization model that allows minimizing delays with respect to the timetable and interval between trains, as well as platform stop and route controls. In addition, there are models that simulate the influence of stop times, stochastic nature, and interference between trains, which will be conditioned by the signalling system.

In this article, we study the influence of both the mathematical model and CBTC technology on the regulation of rail traffic, demonstrating how an improvement in the monitoring of schedules and intervals is obtained, as well as lower energy consumption than traditional regulatory models.

Index Terms: Traffic model; Automatic traffic regulator; CBTC; Continuous communication; Mass transit; Optimization model.

WORKING PAPER

1. Introduction

On a modern metro line, train traffic is regulated from the central command post by sending each train the driving instructions it must carry out. This requires the design of an efficient and precise automatic traffic control model.

Additionally, the implementation of improvements in traffic regulation on metro lines means an increase in the quality of service, both in the maintenance of commercial speed and in regularity and, therefore, increased use of this transport by passengers.

It is with the emergence of CBTC technology at the beginning of S. XXI, when continuous communication between trains is possible, translating into improvements in traffic regulation in terms of time tracking and interval compliance, which motivates the study and development of regulators based on this type of operation.

2. Mathematical Model

The rail traffic regulator is based on a predictive mathematical model of quadratic programming optimization with an objective function that penalizes delays with respect to the schedule, interval deviations and the application of travel and platform stop controls.

$$J = p * \sum_{i,k} \left(Xd_k^i\right)^2 + q * \sum_{i,k} \left(Xd_k^i - Xd_k^{i-1}\right)^2 + a * \sum_{i,k} \left(ur_k^i\right)^2 + b * \sum_{i,k} \left(up_k^i\right)^2 \quad (1)$$

For each train *i:* $1 \leq i \leq N$ and for each platform *k:* $k_{0i} \leq k \leq k_{0i} + L$, where k_{0i} is the next train departure platform *i* and *L* is the number of platforms included in the optimization horizon.

In addition, Xd_k^i is the delay of the train *i* at the departure of the platform *k;* ur_k^i is the action control of the train *i* at the departure of platform *k;* up_k^i is the stop control of train *i* at the arrival at platform *k.*

The action control are constrained as

$$URmin_k \leq ur_k^i \leq URmax_k \quad (2)$$

On the other hand, it has to be fulfilled that the travel control executed on a train has to be equal to the delay of that same train on arrival at the next platform minus the delay at the departure of the current platform

$$Xa_{k+1}^i - Xd_k^i = ur_k^i \quad (3)$$

The delay to the arrival of a train *i* to the platform *k* is conditioned by the delay in the departure from platform *k* of the previous train (*i* - 1). Whereas $Imin_k$ is the minimum departure - arrival interval, whereas s_k is the nominal stop time at platform *k* and whereas *H* is the nominal departure - arrival interval, is obtained

$$Xa_k^i - Xd_k^{i-1} \geq Imin_k + s_k - H \quad (4)$$

Lower limit of platform stop control is considered

$$UPmin_k \leq \mathrm{up}_k^i \quad (5)$$

The stop time at the platforms is considered linear with respect to the departure - arrival interval, as the time required by passengers to get on and off the train increases with the interval. If α_k is considered to be a constant proportional to that range

$$Xd_k^i = Xa_k^i + \alpha_k * \left[Xa_k^i - Xd_k^{i-1}\right] + \mathrm{up}_k^i \quad (6)$$

3. Gear modification for CBTC technology

To implement the CBTC technology, an instance has been developed that modifies the gear that the train is running. The optimization function returns, through the travel controls, a new target time in which the interstation has to travel the train.

If the interstation is controlled by drift – retraction regulation, drift and traction speeds will be modified until the target time is met. If the train is drifting, drift and retraction speeds are reduced, maintaining the nominal difference between them, with the restriction that the minimum retraction speed is 20 km/h.

If the train is drifting, the retraction speed is first reduced and, if it cannot be reduced further, the drift speed is reduced until the target time can be met.

In the event that the interstation is regulated by speed, it is modified to meet the suggested time.