Stability of timing points in automatic train operation

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Abstract

Automatic Train Operation (ATO) facilitates punctual, energy-efficient and reliable train driving by supporting or replacing human drivers. The key to enabling effective ATO deployment is seamless interfacing between the ATO-Trackside and the Traffic Management System (TMS). Specifically, the ATO-Trackside determines timing points at given locations with their associated time targets or windows to be met by the ATO-Onboard train trajectory generation. These timing points must align with the updated real-time traffic plan computed by the TMS for effective scheduling. However, variations in the real-time traffic plan might cause unstable and continuously varying locations and times of timing points. Unstable timing point information could lead to infeasible train trajectory calculation or uncomfortable changes in train driving regimes from the ATO-Onboard. So far, no study has closely analysed such a practical issue relevant to the effective deployment of ATO technologies. This paper tackles this crucial aspect by performing a stability analysis of timing points at the ATO-Trackside versus dynamic updates of rail traffic conditions and real-time traffic plans from the TMS. We first analyse the variation of timing point configuration for different headway times planned by the TMS in line with signalling constraints. Then, we perform an additional sensitivity analysis to identify the variation of timing points with respect to entrance and exit delays as well as dynamic changes in traffic

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states over time. We test the proposed method for the 2023 timetable on one of the busiest rail traffic corridors in the Netherlands. The results show that ATO timing points are stable in locations, whereas their associated time targets or windows require adjusting to the changing situation.

Keywords: Automatic Train Operation, Timing Point, Traffic Management System, Real-Time Traffic Plan, Stability Analysis

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1. Introduction

Automatic Train Operation (ATO) is a technology that automates train driving to increase running time reliability and energy efficiency, facilitating a more capacity-effective and sustainable railway system. ATO consists of two main components: a trackside and an onboard subsystem (Wang et al., 2022). The ATO-Trackside dynamically defines a set of time targets or windows at given discrete network locations called Timing Points (TPs) along the train route in line with infrastructure and timetable information. These time targets or windows at TPs serve as temporal constraints for the ATO-Onboard, where the train trajectory is derived and closely followed.

For effective ATO scheduling, the TP information generated at the ATO-Trackside must respect the reference locations and times either in the original timetable or adjusted schedule known as Real-time Traffic Plan (RTTP) implemented by dispatchers to incorporate actual conditions or disturbances. RTTPs comprise dispatching strategies such as train retiming, reordering and rerouting (Corman and Meng, 2015; Quaglietta et al., 2016), which may alter the planned reference points and times for rescheduled trains. Consequently, ATO TPs for those rescheduled trains would possibly need to be changed accordingly to effectively communicate adjusted locations and times to the ATO-Onboard responsible for train driving. Similar changes in the ATO TP configuration may also be necessary with dynamically evolving traffic conditions over time, particularly when stochastic deviations are observed versus planned speed profiles due to, for example, mismatching train parameters. The consequence of ATO TPs continuously changing with RTTPs updates or with stochastically time-varying traffic conditions might result in infeasible train trajectory calculation or uncomfortable sudden changes in train driving regimes at the ATO-Onboard. Therefore, it is relevant for the ATO-Trackside to provide stable TPs that can enable flexible and conflict-free train operations while not change easily with corresponding updates of real-time traffic states or the RTTP computed by the Traffic Management System (TMS). Although several R&D programmes have been set up on ATO in Europe (EU-RAIL, 2021) and China (Ning et al., 2006), no study has addressed this critical aspect so far, representing a significant concern for the effective deployment of ATO.

To this end, we contribute to this knowledge gap by investigating the stability of TPs from the ATO-Trackside versus dynamic updates at TMS in terms of the traffic states and RTTPs. Specifically, we consider updates in the RTTPs regarding planned headway changes of a successive train pair, train entrance and exit delays at stations, and traffic state updates due to real-time changes in speeds and positions of operating trains. We are testing the proposed methodology in one of the busiest rail traffic corridors in the Netherlands. The results of this paper will be presented at the TRAIL conference.

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