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Real-Time Automatic Train Regulation of Metro Lines With Bifurcations and Short-Turning Under Continuous Communication

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Abstract-

This paper introduces a novel Real-Time Model Predictive Control (MPC) framework for automatic train regulation in complex metro lines featuring bifurcations, short-turning operations, and continuous communication systems (CBTC or ERTMS), enabling real-time information exchange between trains and control centers for traffic supervision and control. This framework addresses a critical gap in existing approaches: enabling the restoration of nominal operations after moderate disruptions when the line is not limited to a simple or looped infrastructure. The proposed approach operates in two stages: first, a predictive mathematical algorithm generates running-time and dwell-time control actions, balancing timetable adherence and headway regularity subject to topological constraints. Second, these actions are processed by a module that generates real-time automatic driving commands. A key contribution is the incorporation of a granular optimization strategy that enhances energy efficiency while preserving operational performance. The algorithm was validated on a simulation platform based on a real Spanish metro line and, compared to traditional regulation, the results demonstrate a 30.00% improvement in headway adherence and a 7.80% reduction in passenger waiting time in high-demand areas, along with a 10.37% reduction in energy consumption. The computational efficiency of the proposed model confirms its suitability for real-time application in large-scale, complex transit infrastructures.

Index Terms- Automatic train regulation, complex topology, energy efficiency, mass transit systems, model predictive control, real-time optimization.

Citation:

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