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Efficiency and Running Time Robustness in Real Metro Automatic Train Operation Systems: Insights from a Comprehensive Comparative Study

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Abstract-

Automatic Train Operation (ATO) systems are widely deployed in metro networks to improve punctuality, service regularity, and ultimately the sustainability of rail operation. Although eco-driving optimisation has been extensively studied, no previous work has provided a systematic, side-by-side comparison of the two ATO control philosophies most commonly implemented in metro systems worldwide: (i) Type 1, based on speed holding followed by a single terminal coasting at a kilometre point, and (ii) Type 2, which uses speed thresholds to apply either continuous speed holding or iterative coasting–remotoring cycles. These strategies differ fundamentally in their control logic and may lead to distinct operational and energetic behaviours. This paper presents a comprehensive comparison of these two ATO philosophies using a high-fidelity train movement simulator and Pareto-front optimisation via a multi-objective particle swarm algorithm. 40 interstations of a real metro line were evaluated under realistic comfort and operational constraints, and robustness was assessed through sensitivity to three different passenger-load variations (empty train, nominal load and full load). Results show that, once nominal profiles are implemented, Type 1 has up to 5% variability in running times, and Type 2 has up to 20% variability in energy consumption. In conclusion, a new ATO deployment combining both strategies could better balance energy efficiency and timetable robustness in metro operations.

Index Terms- automatic train operation; ATO; energy optimisation; metro systems; railway systems; energy efficiency; speed profile design; train simulation; eco-driving; robustness; sustainable transport

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