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Conflict-free train path planning using ATO timing points

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Automatic Train Operation (ATO) is a technology to support or automate train driving for increasing service punctuality, energy efficiency and rail infrastructure capacity. Conflict-free train path planning is crucial to the effective deployment of ATO, which allows ATO-equipped trains to operate according to schedule with different train driving strategies. As different train driving strategies lead to various passing times, current planning practice is inadequate to avoid route conflicts as it only sets target arrival or passing times at stops or major junctions. Therefore, conflict-free train path planning needs the definition of a Train Path Envelope (TPE) that contains time targets or windows defined at discrete locations called timing points to tolerate schedule deviations due to different driving styles. The number and location of the timing points, as well as the associated time targets or windows, is a decision problem. This paper proposes a framework to design a robust set of timing points and their associated time windows in a TPE to enable operational conflict-free train path planning against the driving strategies utilised. This framework relies on a Train Path Slot model which extends the definition of TPE from time windows at a discrete set of locations to an integrated blocking time stairway pattern continuously defined across all locations over a train route. The Train Path Slot model considers three relevant train driving strategies, i.e., energy-efficient driving with or without coasting as well as minimum-time driving considering slight delays. A Linear Programming model is formulated to compute the conflict-free Train Path Slots as constraints for train operation. To meet the optimised Train Path Slots, we analyse several possible sets of timing points in a TPE that are only located at stops or signal positions along the train routes. Those timing point sets are then compared in terms of total Train Path Slot overlap time, capacity, energy efficiency and driving performance indicators. Our research supports infrastructure managers in resolving the imminent problem of timing point determination and TPE computation to reach their capacity goals. At the same time, it allows sufficient driving flexibility for railway undertakings.

Keywords
ATO-over-ETCS, Automatic Train Operation, Train Path Envelope, Train driving strategies, Timing Point