

# **Balancing energy consumption and risk of delay in high speed trains: a three-objective real-time eco-driving algorithm with fuzzy parameters**

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**Abstract—** Eco-driving is an energy efficient traffic operation measure that may lead to important energy savings in high speed railway lines. When a delay arises in real time, it is necessary to recalculate an optimal driving that must be energy efficient and computationally efficient.

In addition, it is important that the algorithm includes the existing uncertainty associated with the manual execution of the driving parameters and with the possible future traffic disturbances that could lead to new delays.

This paper proposes a new algorithm to be executed in real time, which models the uncertainty in manual driving by means of fuzzy numbers. It is a multi-objective optimization algorithm that includes the classical objectives in literature, running time and energy consumption, and as well a newly defined objective, the risk of delay in arrival. The risk of delay in arrival measure is based on the evolution of the time margin of the train up to destination.

The proposed approach is a dynamic algorithm designed to improve the computational time. The optimal Pareto front is continuously tracked during the train travel, and a new set of driving commands is selected and presented to the driver when a delay is detected.

The algorithm evaluates the 3 objectives of each solution using a detailed simulator of high speed trains to ensure that solutions are realistic, accurate and applicable by the driver. The use of this algorithm provides energy savings and, in addition, it permits railway operators to balance energy consumption and risk of delays in arrival. This way, the energy performance of the system is improved without degrading the quality of the service.

**Index Terms—** Delay recovery; Dynamic multi-objective optimization; Eco-driving; Fuzzy logic; High speed railway; Simulation

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