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Train Timetable Rescheduling Using Sensitivity Analysis: Application of Sobol, Based on Dynamic Multiphysics Simulation of Railway Systems

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Abstract : Developing better solutions for train rescheduling problems has been drawing the attention of researchers for decades. Most researches in this field deal with minor incidents that affect a large number of trains due to cascading effects. They focus on timetables, rolling stock and crew duties, but do not take into account infrastructure limits. The present work addresses electric infrastructure incidents that limit the power available for train traction, and hence the transportation capacity of the railway system. Rescheduling is needed in order to optimally share the available power among the different trains. We propose a rescheduling process based on dynamic multiphysics railway simulations that include the mechanical and electrical properties of all the system components and calculate physical quantities such as the train speed profiles, voltage along the catenary lines, temperatures, etc. The optimization problem to solve has a large number of continuous and discrete variables, several output constraints due to physical limitations of the system, and a high computation cost. Our approach includes a phase of sensitivity analysis in order to analyze the behavior of the system and help the decision making process and/or more precise optimization. This approach is a quantitative method based on simulation statistics of the dynamic railway system, considering a predefined range of variation of the input parameters. Three important settings are defined. Factor prioritization detects the input variables that contribute the most to the outputs variation. Then, factor fixing allows calibrating the input variables which do not influence the outputs. Lastly, factor mapping is used to study which ranges of input values lead to model realizations that correspond to feasible solutions according to defined criteria or objectives. Generalized Sobol indexes are used for factor prioritization and factor fixing. The approach is tested in the case of a simple railway system, with a nominal traffic running on a single track line. The considered incident is the loss of a feeding power substation, which limits the power available and the train speed. Rescheduling is needed and the variables to be adjusted are the trains departure times, train speed reduction at a given position and the number of trains (cancellation of some trains if needed). The results show that the spacing between train departure times is the most critical variable, contributing to more than 50% of the variation of the model outputs. In addition, we identify the reduced range of variation of this variable which guarantees that the output constraints are respected. Optimal solutions are extracted, according to different potential objectives: minimizing the traveling time, the train delays, the traction energy, etc. Pareto front is also built.

Keywords : optimization, rescheduling, railway system, sensitivity analysis, train timetable
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