Optimization Approaches for Real-time Mitigation of Power Peaks in Railway Networks using Train Control Measures

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Background

Power peaks are an undesirable phenomenon occurring in railway networks when multiple electric trains require large amount of power simultaneously, for instance, during acceleration. This phenomenon puts too much pressure on the power grid, which in the worst cases it can result into a blackout, and hence it represents a relevant concern for operators (Regueiro Sánchez, 2021). Furthermore, the high fluctuations in power consumption over time have a significant direct impact on operation costs, even though power peaks are generally very short in time (Albrecht, 2014). Reducing energy consumption is anyways a top priority in sustainability policies in many countries.

One solution for this is fine-tuning timetables to minimize power peaks. Nevertheless, the benefits of adjusted timetables can be lost in situations with train delays in the network. In this work, the goal is to develop a new approach to mitigate anticipated power peaks in real-time by means of train control measures, i.e. traction power limitation and departure time shift, combined with real-time rescheduling.

Problem Description

There is extensive literature covering the wide field of energy-efficient railway operations. For a review of different approaches for energy-efficient railway operations, including timetabling and train control, we refer to Albrecht (2014) and Scheepmaker et al. (2017). Regueiro Sánchez (2021) developed a simulation-based optimization approach combining two train control measures: of power limitation and departure time shift. The results showed great potential to reduce the power peaks, particularly by means of limiting the maximum traction power of the trains. This approach is further extended in Trepat et al. (2023) with heuristics to explore the search space more efficiently and hence reduce computational times for a real-time application.

The goal of this project is to develop a pure optimization approach for the problem of mitigating power peaks in railway networks using train control measures in real-time, possibly including train delays. This optimization approach will be made in the form of a mixed-integer linear program. We consider power limitation and departure time shift as possible train control measures. The problem minimizes the total induced delay while capturing all relevant constraints that model feasible railway traffic (block sections, single and double track sections, technical headways between trains, train conflicts, etc.) (Pachl, 2014), for which we need to use detailed infrastructure models (Radtke, 2014). The approach will be tested in a case study consisting of the line between Giubiasco and Locarno (Canton Ticino) of the Swiss Federal Railways.

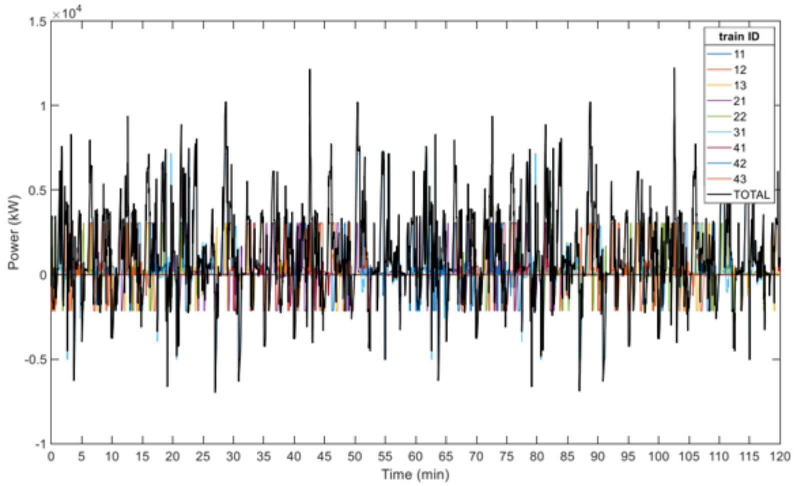

Figure 1: Simulation of power consumption of multiple trains over time (Regueiro Sánchez, 2021).

Research Questions

The main research question of this project is the following: Can the Real-time Mitigation of Power Peaks in Railway Networks using Train Control Measures problem be formulated and solved efficiently using a pure optimization approach? Furthermore, the goal is to evaluate whether the approach performs better than a simulation-based optimization approach. Follow-up research (sub)questions can be formulated by the student.

Approach

The student will be given the data required for this project (infrastructure information, train timetables, power consumption and speed profiles) and a tentative mathematical formulation of the problem as a mixed-integer linear program. The student will implement the mathematical model in Python with Gurobi and make the necessary adjustments / tuning to the model if needed. The results of the computational experiments will be benchmarked against the simulation-based optimization approach from Regueiro Sánchez (2021) and Trepat et al. (2023). The student is expected to have knowledge in coding with Python and Gurobi.

References

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