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Next generation train control: online calibration of train motion models and stochastic optimization of train trajectories

The on-board collection of data related to train operation opens new perspectives for the enhancement of train motion models, which constitute the backbones for the elaboration of traffic management solutions. Online calibration of the train motion models allows capturing all those non modelled resistance components that affect energy consumption and travel time. Stochastic optimization of train trajectories will allow enhancing the reliability of solutions, thus allowing a more adherent operation to scheduled and rescheduled conditions. Coupling online calibration and stochastic optimization of train trajectories allows a better use of infrastructures' capacity and an effective implementation of energy saving strategies. Moreover, it enable a full exploitation of autonomous driving technologies (e.g. ATO) for their application on main lines. All the elaborations have been made with the support of SBB, in terms of data collection and analysis.

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Introduction

In the last years, the optimization of rail operation for different purposes (e.g., increase of network use, increase of punctuality, increase of energy efficiency) has become a primary goal for railway systems to keep being competitive in the transportation market (Corman and Meng, 2015; Rao et al., 2016). New technologies and advanced modelling contribute to achieving performance goals. Nevertheless, these must be associated with a higher specification of the train motion models for their effective and correct use, with the aim to obtain more accurate results and adherence to reality.

Therefore, the online calibration of train motion models and the adoption of stochastic optimization models for energy efficient driving are key aspects for a complete specification of different train operation conditions and thus, for a more accurate solutions generation.

Online calibration of train motion models

Differently from track resistances (e.g. curves, gradients), vehicle resistances are usually expressed with a trinomial speed-dependent formula (1) , which considers train characteristics through parameters *A*, *B* and *C*.

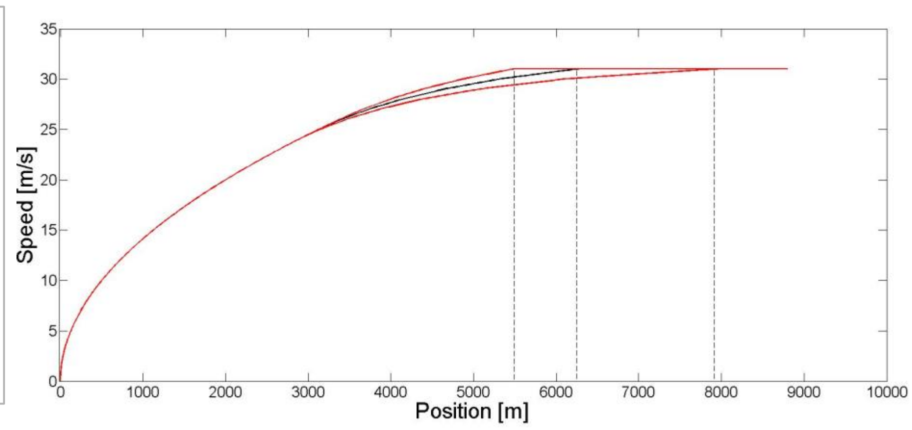
$$R(v_t) = A + Bv_t + Cv_t^2 \qquad (1)$$

The parameters' values *A*, *B* and *C* are also computed following consolidated, old formulations, which cannot satisfy the required precision for enhancing rail system performances. Instead, online calibration of these values through tractive efforts information allows for an "ad hoc" specification of the train motion.(De Martinis and Corman, 2019).

Figure 1. An example:
For reaching the same target speed, 2 different runs (**red** lines) of the same train type on the same track may have:

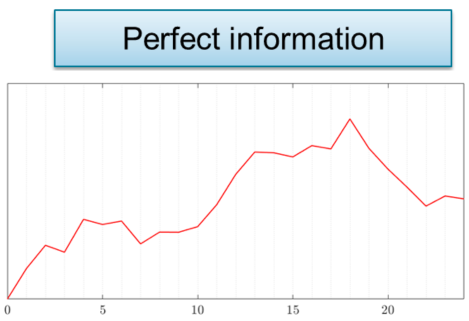
- 2.5 km gap in space.
- Over 90 seconds gap in time.
- Over 34% gap in energy consumption.

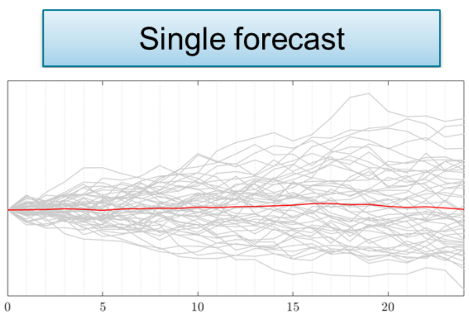
The train motion modeled with the consolidated formulation (**black** line) does not consider these differences



Stochastic optimization of train trajectories

The current train trajectory calculation is mostly based on a deterministic optimization (i.e. perfect information and single forecast), which can neither accommodate random variables (e.g. driving behavior or weather.) nor explicitly account for stochastic constraints. If a solution to the optimal control and trajectory planning is based on wrong parameter values, its outcome might be suboptimal, or even infeasible. The use of stochastic optimization approaches accounts for uncertainty explicitly by considering it in multiple forecasts (Wang et al., 2019).





Expected impact

Next generation train control must enhance traffic performances through a better use of the infrastructures and a more precise and reliable traffic management. In Switzerland this is even more difficult due to the already very dense traffic and the high precision in train operation.

The combination of online calibration of train motion models and stochastic optimization of train trajectories will allow releasing an additional 15-25% infrastructure capacity and saving 15-20% energy consumption overall, with increased punctuality on the entire system (De Martinis and Corman, 2018).

It is worth to highlight that online calibration of train motion models and stochastic optimization of train trajectories are particularly suitable for the use of Automatic Train Operation systems and their future implementation on mainlines.

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