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Abstract

Railway traffic usually adheres to a timetable, but in Sweden, around two-thirds of the freight trains depart before they are scheduled, often by hours. Even though they occur in real operations, early departures have rarely been included in simulation studies and the effects on punctuality are not fully investigated. With a macroscopic simulation tool such as PROTON, large networks can be simulated in a short time, which makes the simulation process easier. This paper uses the tool PROTON to perform a macroscopic simulation case study on the Swedish Western mainline to investigate how early departures of freight trains affect punctuality. The resulting output is a marginal overall punctuality improvement of about +0.5 percentage points. In addition, different levels of primary run time and dwell time delays have been used as simulation input, based on empirical data. The resulting ratio between primary and secondary delays appear to vary greatly between different train types, but overall about 30% were primary and 70% secondary. Future work includes modelling and calibration of departure deviations, which vary more between different train types, and where it is more difficult to separate between primary and secondary delays. Separating distributions based on train type or location will also be considered.

Keywords: railway traffic, freight trains, macroscopic simulation, early departures, delays

1. Introduction

For railway traffic, adherence to the planned timetable is important for operators and traffic managers, as passengers and freight customers expect departures and arrivals to take place as scheduled. Thus, punctuality is an important metric to evaluate the railway traffic, often accompanied with punctuality level goals to attain. However, not all deviations from the timetable stem from unfortunate delays.

In Sweden, about two-thirds of freight trains depart ahead of schedule, sometimes hours ahead. Traffic managers perform departure dispatching in real-time, often as the freight trains report being ready. There are several reasons as to why freight trains are ready to depart ahead of schedule, just as there are several reasons why they are not ready to depart on time. One reason is that freight train operations contain many dependencies, for example, transfers of freight wagons between trains at both larger and smaller rail yards, and sometimes these lead to large deviations in either direction. However, dispatching decisions that deviate significantly from scheduled operations invalidate the often-extensive planning work done by timetable planners and can place a significant burden on downstream traffic managers. This extra burden can be justified if the overall effects in terms of punctuality are positive, as indicated by, e.g., [1] and [2], but further work is needed to verify the results and to investigate the effects in more detail, e.g. on the train type level.

This paper uses a simulation case study approach to quantify the punctuality effects of the practice of allowing early freight train departures compared to not allowing them. Moreover, the level of primary delays in the empirical delay data is investigated through simulation of a range of primary delay levels.

1.1 Related work

Simulation of railway traffic and the effects of disturbances is often performed with microscopic tools such as RailSyS [3], [4], OpenTrack [5], LUKS [6], or Trenissimo [7]. Microscopic simulation includes a high level of detail while the computation time suffers. This makes it difficult to simulate large networks. Therefore, macroscopic simulation can be a practical alternative, where fast simulation over large networks can be performed due to less detailed modelling of infrastructure and vehicles. Macroscopic models have been proposed [8], most notably the simulation tool PROTON (previously known as PRISM) [9], [10].

Various aspects of delay distributions have been studied around the world. Focussing on a Swedish context, passenger train delay distributions [11] and freight train delay distributions [12] have been identified and analysed. Attempts have been made to distinguish primary delays from empirical data [13], including calibration and validation for RailSys simulation on the Western mainline [14].

Effects of allowing or not allowing early freight train departures have been studied empirically [1], but also regarding how to include early departures in simulations [15]. Recently, both microscopic RailSys simulation and Macroscopic PROTON simulation have been compared, with and without allowing early freight train departures, and with a rough estimate of the primary delays to 1/3 of the empirical delays on the Swedish Southern mainline [2]. The simulation results were closer to the empirical punctuality data when the freight trains were allowed to depart early.

2. Method

In microscopic simulation models, the infrastructure is modelled in relative detail. This includes for example the track layout, signal positions and train protection system, and vertical profile. Consequently, the train movements can also be modelled in relative detail. However, the amount of detail results in long simulation times when larger networks are considered.

In this paper, however, we use PROTON (Punctuality and Railway Operation Simulation), which is a macroscopic railway traffic simulation tool developed by DB Analytics (Deutsche Bahn AG) in the Shift2Rail projects PLASA and PLASA-2. One of the main goals was that the tool would be fast even on very large networks. PROTON is currently being introduced at Trafikverket (the Swedish Transport Administration). The tool was formerly known as PRISM (PLASA Railway Interaction Simulation Model).

The macroscopic infrastructure in PROTON is built up of nodes and edges. The nodes typically represent the operating stations while the edges link these. The station track layout including the number of tracks is not modelled. However, it is indicated whether additional tracks for train overtaking are available or not and the direction in which this applies. The edges have information about, among other things, length, number of tracks, maximal speed, and type of train protection system. Train type information provides some basic train properties such as acceleration/deceleration, length, and weight. The timetable specifies the sequence of nodes and the respective scheduled arrival and departure times to these, train type, train ID and available allowance for each train. Distributions are used to model different types of disturbances in simulations, mainly initial/entry, dwell and edge disturbances. Interferences between trains (conflicts) are modelled based on minimum headway times. A detailed description of how PROTON works can be found in [10].

2.1 Case study

The Swedish Western mainline connects the two largest cities in Sweden, the capital Stockholm and Gothenburg. The section Hallsberg–Gothenburg on this mainline is selected for the case study (see Figure 1). The line is double-tracked and the traffic consists of a mix of high speed, regional and local passenger trains as well as freight trains. Sweden's largest freight yard is located at Hallsberg and the Port of Gothenburg is the largest port in Scandinavia.

Figure 1: Map showing the Swedish Western mainline Stockholm–Gothenburg, the section used in this study (Hallsberg–Gothenburg) in red.

Two days from the production timetable from the year 2019 are simulated in this study, one Thursday and one Saturday. The main purpose is to simulate two days with different timetables. Two main scenarios are simulated for each day. In the first scenario, freight trains are initiated according to the full historical distributions, i.e., they can depart both ahead and behind the scheduled time as in reality. In the second scenario, freight trains are not initiated ahead of schedule, the part of the distributions giving values ahead of schedule is adjusted to give a zero value instead, i.e., on schedule. This setup gives in total four main scenarios, each of these is then further split into 19 cases (sets) with different scalings on dwell and runtime delay distributions, from 5% to 100% (see Section 2.3). In total, 76 scenarios were simulated.

2.2 PROTON setup

In this study the timetables are selected, date and area, from the year 2019 production timetable which was planned and managed in TrainPlan (Trafikverket's timetable planning system), and converted to a format PROTON reads. Trains may sometimes have negative allowance on edges, meaning that the scheduled driving time is less than the minimum driving time. This does not matter in practice because there is usually a positive allowance on other surrounding edges that compensate. However, this needs to be taken care of during the conversion to PROTON format to avoid errors in the simulations and therefore the conversion needs to make small corrections in the timetable and redistribute allowance between edges to remove negative allowance.

The minimum technical driving times are compiled to PROTON format from Tigris which is a system for calculating driving times on all timetable edges for all train types used in the TrainPlan environment. The minimum driving times are needed to model delay reductions in relation to scheduled driving times since the PROTON version used does not calculate any driving times itself. The macroscopic infrastructure description for PROTON is converted from a national RailSys model (microscopic) maintained by Trafikverket. Train types (vehicle data) are also converted from this model. These correspond to those used in TrainPlan. **Error! Reference source not found.** describes the data sources and simulation setup used in this study.

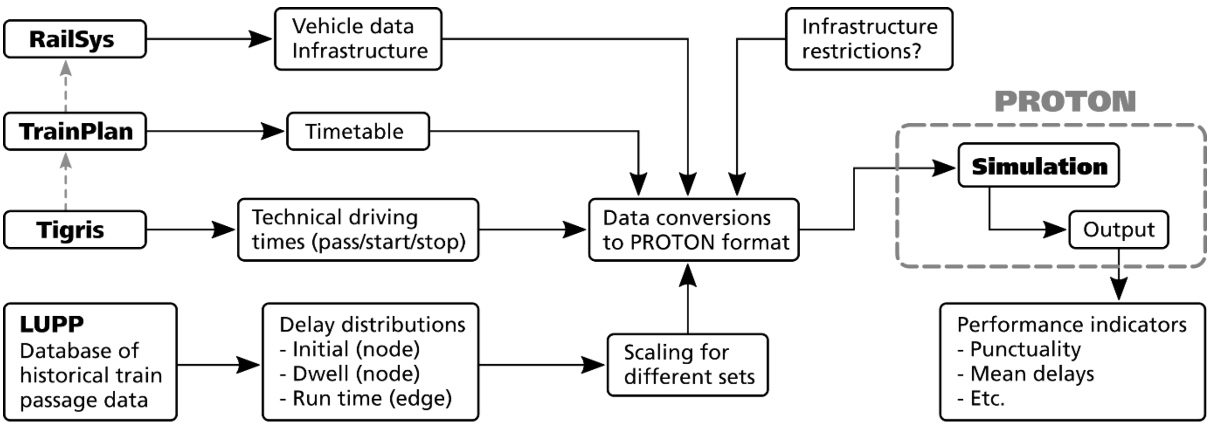

Figure 2: Data sources and simulation setup.

Distributions for modelling stochastic variation (delays) of different types are originally compiled from historical data (LUPP) and scaled for the different simulated scenarios according to Section 2.3. Although not used in this study, there is a possibility in PROTON to define infrastructure restrictions to model the impact of track work, for example, reduced speed and/or reduced number of tracks on edges. All necessary input data is converted to different files and formats required by PROTON. Simulation output contains, among other things, timestamps for each train, node and simulation run. This data needs to be processed to determine the desired measures of performance for different train groups.

2.3 Delay distributions

Several sets of primary delay distributions were created and fed into PROTON. Distributions were created for departure time, dwell time and runtime deviations. For each of these, we separated between freight and passenger trains, and the up (northbound) and down (southbound) directions, so that there are four combinations per distribution, see Figure 3. These were created from empirical data on the studied line Figure 1 from the year 2019. These data contain both primary and secondary delays, with no clear way of separating the two. To only input primary delays into the model, we created a set of scaled-down versions of the dwell- and runtime delay distributions. The frequency of a particular delay was thus multiplied by a factor ranging from between 5 and 100 per cent. A value of X per cent here means that X per cent of the delays are primary, and 1 - X are secondary. The probability mass reduced by the scaling was instead shifted to the activities being on time. Notably, departure deviations were not scaled down in this way, because the simulation tool does not currently keep track of resource (staff or rolling stock) associations between train numbers, and so does not generate secondary departure delays at origin stations. The pure, non-scaled distributions are shown in Figure 3.

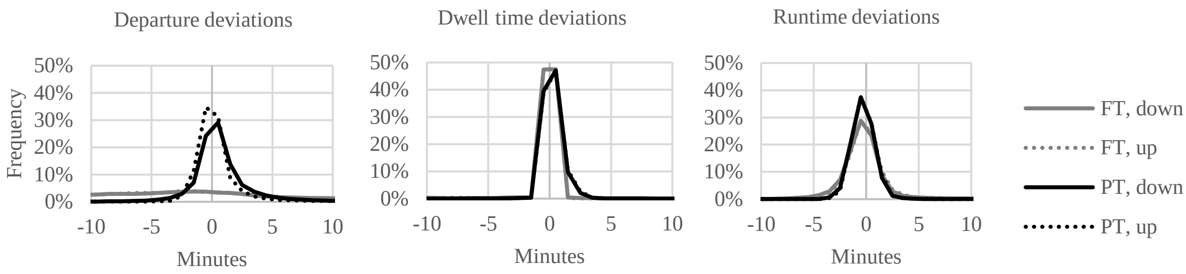

Figure 3: Distribution of departure, dwell time and runtime deviations, from empirical data. The figures are cropped, the distributions used are covering the range -60 to +60 minutes.

3. Results and evaluation

Figure 4 shows that the scenario where dwell- and runtime delays are scaled to 30%, implying 70% secondary delays, fits best with the empirical data. The lines representing the simulated punctuality, with or without early freight trains, then intercepts the line representing the empirical punctuality. It also shows that the benefit of allowing freight trains to depart early diminishes as the primary delays are scaled-down, shrinking from about 1.3 percentage points towards 0, and being about 0.4 percentage points at the most likely level.

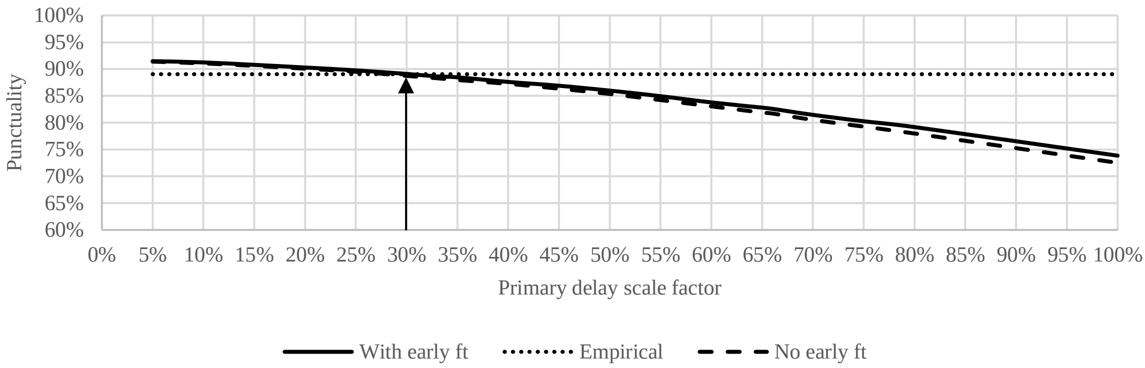

Figure 4: Simulated and empirical punctuality aggregated across days, directions and train types for different primary delay scaling factors. Punctuality is weighted by the number of movements, giving more equal weight to the four different train types. Weighting by the number of trains, as is more conventional, gives excessive weight to local trains, which are least well captured by our simulations.

Figure 5 instead shows how the results break down by train type, focusing on the scenario allowing for early freight train departures. It suggests that the simulation experiments works reasonably well for high-speed & long-distance trains, as well as for freight trains, but less so for regional trains. For local trains, the lines do not intercept at all. Our investigations suggest that this is because the local trains have higher departure punctuality in practice than in the simulations. In future work, further attention needs to be paid to the departure punctuality of simulated trains: the different train types do not differ much in terms of dwell- or runtime delays, but they do differ regarding departure delays.

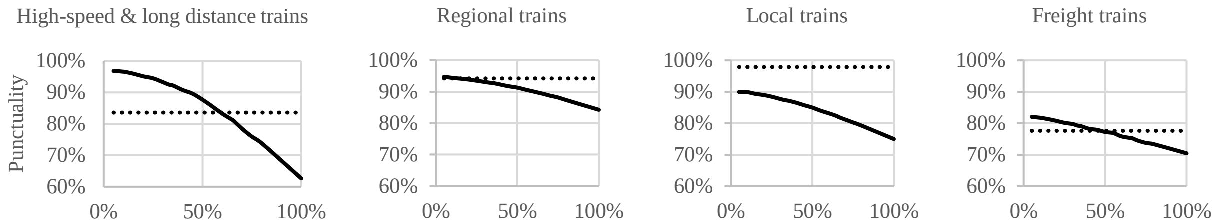

Figure 5: Simulated punctuality by train type for different primary delay scaling factors. The dashed line is the empirical punctuality.

4. Discussion

PROTON is a powerful tool for simulating railway traffic, especially on a network level. Multiple cases on large networks can be simulated in a short time. An obvious disadvantage is of course that the station capacity may be overestimated, i.e., the effects from trains interacting with each other due to crossing movements and lack of available tracks are underestimated. However, this can be compensated by the scaling level of some of the delay distributions used. The main purpose with the scaling of the distributions, which is done in this study, is to find an approximate level of primary delays but also partly to compensate for secondary delays coming from train interactions that are not modelled in the macroscopic simulation.

The distributions used for creating initial (entry) delays are not scaled, i.e., they represent the actual historical data. For trains running from outside and entering the simulation model area, the initial delay distributions represent an accumulation of previously occurring primary and secondary delays. However, for trains starting inside the model area, the initial delay distributions should ideally represent only primary delays while the secondary delays are generated in the simulation. Provided that the original data do not differentiate between primary and secondary delays, as is the case in this study, there is a reason to also scale down initial distributions to approach the primary delay level. One conclusion made from analysing the simulation results in this study is to differentiate, especially initial distributions, between passenger train categories and, where appropriate, also on location.

A natural next step is to differentiate more on train categories and locations as mentioned, i.e., lower the level of aggregation when distributions are compiled. Although two different timetables (Thursday and Saturday) were simulated, no differentiation was made for the distributions, and simulation results were also merged in the analysis. Differences between different days and timetables will also be investigated in the future. When it comes to scaling of the distributions, it is also not a given that the same scaling simultaneously for passenger and freight trains is the best approach to find the level of primary delays from the historical data. These could instead be done in different combinations.

The PROTON version used in these simulations can only handle a macroscopic infrastructure description but DB Analytics is currently working towards PROTON also being able to handle in part microscopic infrastructure, primarily with the aim of modelling station capacity much more realistically than in the pure macroscopic mode.

5. Conclusion

In this paper, we have simulated two operational days and timetables on the Swedish Western mainline in the macroscopic tool PROTON. We have experimented with different levels of primary run and dwell time delays to calibrate the simulation, based on empirical data from 2019. The ratio between primary and secondary delays appears to vary significantly between different types of trains and operational conditions, but overall we found that about 30% were primary and 70% secondary. We also found that allowing freight trains to depart ahead of schedule resulted in a marginal improvement of about +0.5 percentage points to overall punctuality. Future work will focus more on modelling and calibrating departure deviations, which vary more between different train types, and where it is more difficult to separate between primary and secondary delays.

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