Energy Savings with Enhanced Static Timetable Information for Train Drivers

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Abstract

On the network of the Swiss Federal Railways (SBB) there is huge variability in the energy consumption for comparable train runs. Consequently, there is a significant potential to achieve energy savings in the context of improved driving strategy, which can be influenced by providing useful information to the train driver. As part of the smartrail programme operated by the Swiss railway industry, several energy savings measures are due to be implemented. As a first step in the smartrail energy measures, SBB conducted a pilot test in summer 2018. This pilot involved 473 test runs on two important passenger trains in Switzerland: the long-distance train IC5 and the local train S12. For each train run, based on effective routing, train composition, speed restrictions and timetable fixed points, a speed profile and new service times for each station were calculated early each morning for all the train runs of the day.

A survey among the test train drivers showed that more than 80% of them would welcome the rollout of the additional information in the near future. A comparison of the accompanied journeys against the 'baseline', i.e. same trains in the same period without additional information, shows a significant reduction in energy consumption without affecting punctuality: depending on the train journey, the accompanied runs consumed between 1.4% and 13.3% less energy per gross tonne-kilometre.

The high levels of acceptance by the train drivers combined with the significant energy savings achieved without affecting punctuality is very promising. For this reason, a system-wide rollout is currently being investigated and could be started by late 2019.

Keywords
Energy consumption, Timetable, Train control, Traffic-Management System, Train Driver

1 Introduction

Swiss Federal Railways (SBB) operates one of the most dense-running mixed traffic networks in the world. There is huge variability in the energy consumption of similar train runs. On train runs with a comparable duration on the same line, energy consumption can vary by approximately 50% (see Figure 1). Part of this variability can be linked to driving strategy. This illustrates that there is significant potential to generate energy savings through improved driving strategy, which involves providing useful information to the train driver.

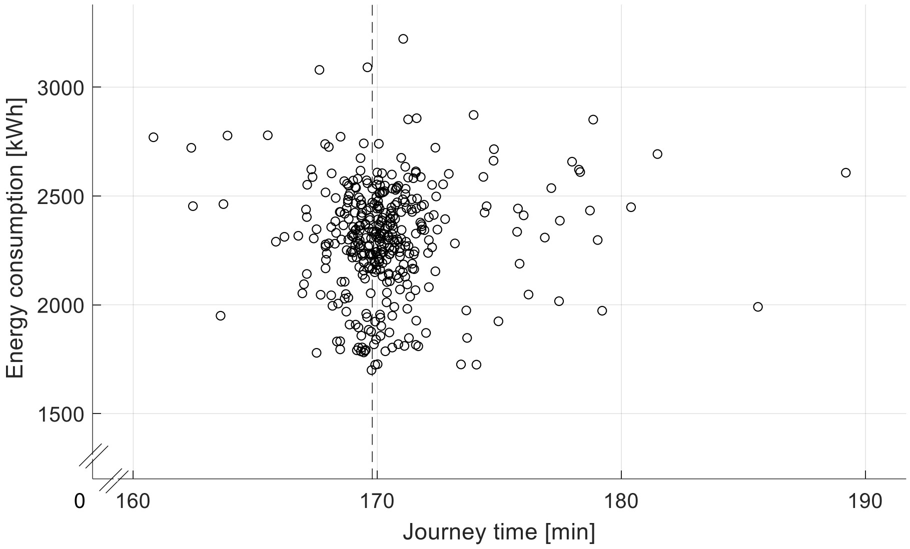


Figure 1: Energy consumption vs journey time on the line Zurich-Geneva Airport from December 2015 to August 2016. The dashed line indicates the nominal journey time.

Driving strategy is usually improved using driving advisory systems (DAS). During a preliminary pilot project by BLS (BLS (2019)) in spring 2017 (Studer et al (2017)), two different DAS with coasting capabilities were compared to an initial version of a static speed profile solution provided by SBB. For this pilot project, SBB provided the static speed profile solution and was responsible for comparing the energy consumptions of the three systems. Surprisingly, even though – from a theoretical point of view – the solutions with coasting capabilities should need less energy for a given running time, the static solution showed comparable energy savings in practice.

In 2017, SBB, together with other railway companies in Switzerland, started a digitalisation programme named smartrail (smartrail (2019)). As part of this programme, a range of different measures will be implemented with the aim of achieving energy savings and improving energy consumption. As a preliminary step for smartrail, SBB decided, based on the findings of the study with BLS, to enhance the traffic management system RCS with static speed profiles. This paper explains how the static speed profiles are calculated and presents the results of the first operative tests. Thanks to the relative simplicity of the static profile, a rollout on the SBB network could be realised within a short amount of time.

2 Methodology and Calculation of Speed Profiles

SBB conducted a pilot test in summer 2018, from the 20th of August to 22nd of September. Overall, 473 test runs were performed on two important passenger trains in Switzerland: the long-distance train IC5 on the line Zurich–Olten–Biel–Geneva and the local train S12 on the line Brugg–Zurich–Winterthur. For the tests, the regular train drivers were accompanied by a representative from the project, who presented and explained the new timetable information.

2.1 Fixed Points and the Algorithm for the Speed Profile

Typical timetable planning in Switzerland begins with a calculation of the minimal running time between stations. Based on these minimal running times, linear time margins are added to the running times of passenger trains (typically 7%). Then, based on knowledge of actual traffic situations and expected delays, the time margins are changed to ensure higher levels of punctuality and traffic stability. After these steps, there is no related speed profile that considers the arrival, departure and passing time for all stations. The time margins are dimensioned in the form of percentages or absolute values without linking back to any speed profile for train driver.

In 2006, based on the real-life experiences of train drivers, SBB developed an algorithm that can reconstruct a feasible speed profile for a given train timetable. The key element in this calculation lies in identifying the stations where the times must absolutely be respected and the stations where a slightly adapted time has no significant negative effect. The stations where times must be respected are called fixed points. For the SBB pilot, we conducted interviews with planners and train dispatchers to identify the fixed points. Fixed points are typically stations with train conflicts, train connections and journey start or end points.

Knowing the target running time between the fixed points, an algorithm reduces the maximum speed in increments until the target running time is achieved. This algorithm considers only acceleration, braking and running at a constant speed, without factoring in coasting capabilities. It is important to mention that the braking phase of the static speed profiles is calculated with the use of regenerative braking, as SBB trains run on 15 kV AC. Working between each pair of fixed points, the algorithm can compute the new static speed profile for each train run, ensuring that the planned times are complied with the fixed points. At this stage, we also allow for slight time deviations from the annually planned times in day-to-day operations at stations which were not identified as fixed points. The small deviations from annually planned times is not a problem, because SBB doesn’t communicate planned times to passengers. We communicate commercial times to passengers which are set so early that, the trains cannot depart earlier than them. The algorithm is configured so that the results are very easy to achieve for a train driver thanks to restricting speed changes to well-known positions on the track. Therefore, an additional train positioning system is not needed.

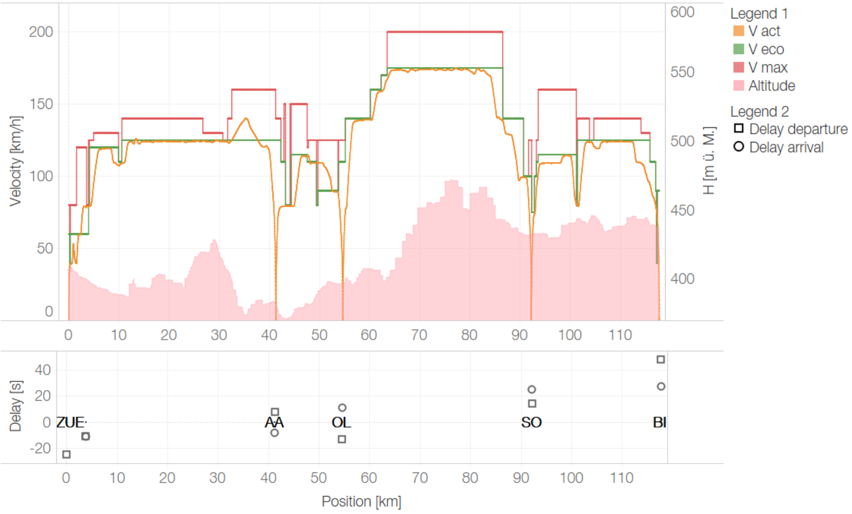


Figure 2: Example of energy-saving train run of IC5 between Zurich and Biel; the green line shows the daily computed static speed profile and the yellow line shows the actual speed profile for a train run.

As can be seen in Figure 2, the green line of eco speed did not factor the option of coasting into our daily computations of speed profiles. This is because we chose a static solution without train positioning and live delay calculation; without positioning, it is quite difficult to precisely determine when to coast for a punctual arrival. Furthermore, the train drivers are still allowed to coast with this static system and should consider the new eco speed profile information as the mean speed to achieve the target times.

2.2 Daily Calculation of Speed Profile

The daily calculations were conducted early each morning for about 100 test train runs using a special extended version of the system RCS. For each train run, a speed profile and the corresponding service times were calculated, based on effective routing, train composition, daily speed restrictions and timetable fixed points.

As shown in Figure 3, instead of annual timetable information without speed profiles, the daily computation provided the new information to be used for the tests. Within the RCS system, the exact routing, all speed restrictions due to maintenance on the network and all daily rolling stock information are provided for all trains. Enhanced with fixed point information, this daily computation delivers feasible and easily comprehensible timetable information for the train drivers:

- For each train run, there are timetable fixed points which must be respected to ensure that the operation remains conflict-free.
- Based on these identified fixed points, an algorithm creates a static speed profile which respects the fixed timing points and temporary as well as static speed restrictions.

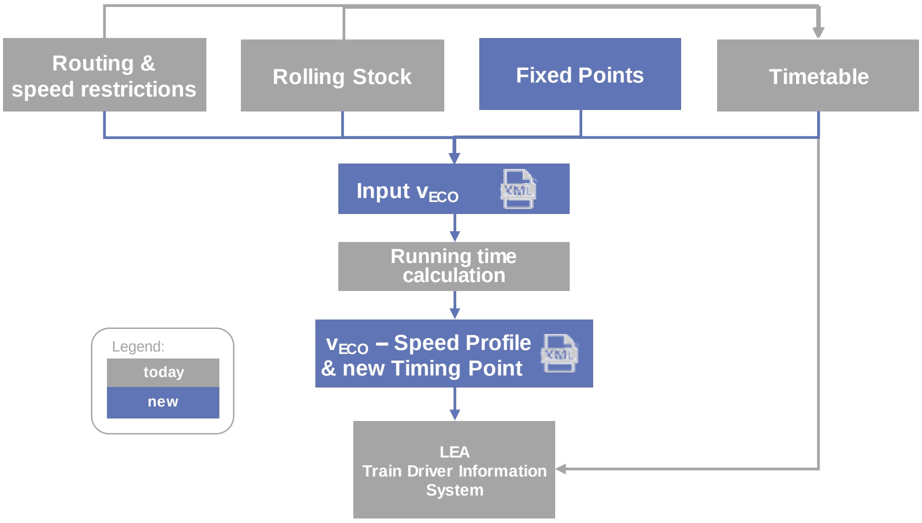


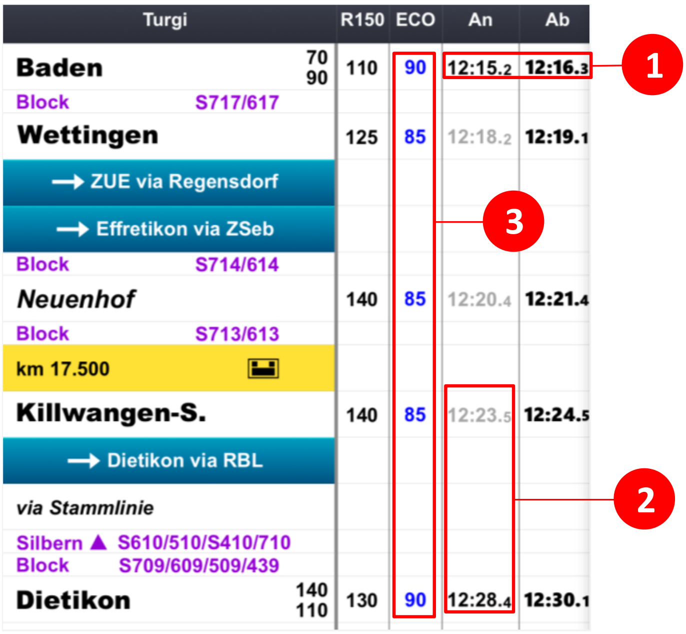
Figure 3: System overview for daily calculation of speed profiles.

2.3 Presentation to the Driver and Advice for the Test

The improved and extended timetable was provided to the train drivers using an adapted version of their usual train driver information system LEA (LEA (2013)). The new information for each test train run was:

- Planned timing point shown to an accuracy of 10 seconds instead of the usual 1 minute (Point 1 on Figure 4)
- For each station/stop daily calculated service times were shown instead of the annual commercial times (Point 1 on Figure 4)
- Important stations for conflict-free operation were marked down (Point 2 on Figure 4)
- The static speed profile for punctual operation was recalculated every day (Point 3 on Figure 4)

The train driver was asked to follow the suggested speed whenever the departure was on time. In the event of a delay, the train drivers were free to choose their own strategy to get the train back on time, as it is the case today on any train run. The conflict detection system of the traffic management system RCS (Rail Control System) (RCS (2019)) was active during the tests. This system is known as ADL (Adaptive Steering) (RCS ADL (2019)) and in the event of any conflict, the train driver was obliged to follow the advice given by the system as usual.



Turgi		R150	ECO	An	Ab
Baden	70 90	110	90	12:15.2	12:16.3
Block S717/617					
Wettingen		125	85	12:18.2	12:19.1
→ ZUE via Regensdorf					
→ Effretikon via ZSeb					
Block S714/614					
Neuenhof		140	85	12:20.4	12:21.4
Block S713/613					
km 17.500					
Killwangen-S.		140	85	12:23.5	12:24.5
→ Dietikon via RBL					
via Stammlinie					
Silbern ▲ S610/510/S410/710 Block S709/609/509/439					
Dietikon	140 110	130	90	12:28.4	12:30.1

Figure 4: Example of enhanced train driver information.

3 Results

3.1 User Experience

The regular train drivers completed a questionnaire on the acceptance of the newly displayed information, focusing primarily on the optimised driving profile. In total, 242 train drivers responded to the questions, which represents 92% of the accompanied drivers from the test.

- 93% of train drivers state that they can implement the optimised driving profile well to very well.
- On average, 80% of the train drivers would welcome a rollout of the new timetable information in the near future.

There are some differences in the responses depending on the experience of the train driver and the type of rail traffic: Experienced train drivers tended to state that they already knew the static speed profile based on personal experience. Less experienced train drivers welcomed it more readily, viewing it as a shortcut to build up their own experience. In regional traffic, acceptance was generally higher than in long-distance traffic. We assume that the demands placed on regional drivers are greater and the workload of these drivers is higher, so any assistance is more appreciated.

3.2 Energy Consumption

Most of the trains were equipped with energy measurement devices with a temporal resolution of one second, which allowed us to perform a precise analysis on the train runs. The total amount of consumed energy for an individual train run was determined by summing up the energy consumption from the start to the end time of the train run, as provided by the traffic management system RCS.

In the following section, energy consumption with or without application of the static profile is compared for the different tracks and directions. ‘Eco’ refers to cases where the static profile was provided, whereas ‘baseline’ refers to normal cases without any additional input provided to the train drivers. Statistical significance tests were performed for all the comparisons carried out.

To obtain comparable values, the energy consumption of every single train run was converted to a specific energy consumption value in Wh/Gtkm, with additional correction applied to cover the difference in altitude between the start and end stations, i.e. subtraction of the corresponding gravitational potential energy (referred to below as potential energy).

Local train between Brugg and Winterthur (S12)

A total of 276 runs were conducted during the test period. 159 of these runs were ‘baseline’ runs and 117 were ‘eco’ runs. Table 1 provides an overview of the test setup.

Table 1: Overview of test setup for S12

RABe 511 (Regio-Dosto)	**Distance**	**Average weight**	**Δ Potential energy**	**Journey time**
Brugg→Winterthur	56.6 km	306.8 t	72.5 kWh	55m 36s
Winterthur→Brugg	56.6 km	306.8 t	-72.5 kWh	54m 42s

Table 2 shows the specific, altitude-compensated energy consumptions of single train runs for the S12 in both directions. The reduction in energy consumption in the direction Brugg–Winterthur is more pronounced than in the other direction. We suppose that this is the case because the timetable for the direction Brugg–Winterthur allows for more scope for optimisation.

Statistical Significance of the Differences

The statistical significance of the differences between the ‘baseline’ and ‘eco’ runs was estimated using the null hypothesis that there is no difference between ‘baseline’ and ‘eco’. Table 2 provides an overview of the results. Numbers in Wh/Gtkm denote median specific, altitude-corrected energy consumptions. Percentages denote relative differences between the ‘baseline’ and ‘eco’. Bold-type percentages indicate significant results based on Wilcoxon rank-sum tests with significance level of 5% and p-values $p<0.01$. Statistically significant differences were obtained for both directions.

Table 2: Overview table of results for S12 energy consumption

Brugg–Winterthur	**-13.3%**
‘baseline’	26.3 Wh/Gtkm
‘eco’	22.8 Wh/Gtkm

Winterthur–Brugg	**-7.6%**
‘baseline’	26.4 Wh/Gtkm
‘eco’	24.4 Wh/Gtkm

Long-Distance Train between Zurich and Geneva (IC5)

For the evaluation of the long-distance IC5 trains, the analysis was sub-divided into segments.

- For both directions, the track was split in Biel, where there is often a change of train driver or train composition (single-unit to double-unit or vice versa)
- We differentiated between single-unit and double-unit trains due to the increased efficiency of double-unit trains observed on tracks with high maximal allowed speed (as compared to local trains with lower maximal allowed speed).

A total of 1406 runs were completed in the test. 1079 of these runs were ‘baseline’ runs and 327 were ‘eco’ runs. Table 3 provides an overview of the test setup for the four segments.

Table 3: Overview of test setup for IC5, direction Zurich–Geneva, with two segments.

RABDe 500 (ICN)	**Distance**	**Average weight**	**Δ Potential energy**	**Journey time**
Zurich→Biel	117 km	365.6 t	29.27 kWh	62min 18s
Biel→Geneva	152 km	365.6 t	- 44.9 kWh	81min 18s
Geneva→Biel	152 km	365.6 t	44.9 kWh	80min 42s
Biel→Zurich	113.2 km	365.6 t	-22.27 kWh	62min 48s

Statistical Significance of the Differences

The statistical significance of the differences between the ‘baseline’ and ‘eco’ runs was once more estimated using the null hypothesis that there is no difference between ‘baseline’ and ‘eco’. Table 4 provides an overview of the results. Numbers in Wh/Gtkm denote median specific, altitude-corrected energy consumptions. Percentages denote relative differences between the ‘baseline’ and ‘eco’. Bold-type percentages indicate significant results based on Wilcoxon rank-sum tests with significance level of 5% and p-values $p<0.025$. Significant differences were obtained for five out of eight sets.

Table 4: Overview and comparison of median specific, altitude-corrected energy consumptions. Percentages denote relative differences between ‘baseline’ and ‘eco’.

	Single-unit train	**Double-unit train**
Zurich - Biel	**-3.0%**	*-1.4%*
‘baseline’	134 runs: 23.0 Wh/Gtkm	133 runs: 21.9 Wh/Gtkm
‘eco’	55 runs: 22.3 Wh/ Gtkm	29 runs: 21.6 Wh/ Gtkm

Biel - Genf	**-2.0%**	*-2.6%*
‘baseline’	175 runs: 19.7 Wh/Gtkm	92 runs: 19.0 Wh/Gtkm
‘eco’	60 runs: 19.3 Wh/Gtkm	22 runs: 18.5 Wh/Gtkm
Genf - Biel	*-2.0%*	**-4.2%**
‘baseline’	171 runs: 19.9 Wh/Gtkm	99 runs: 19.1 Wh/Gtkm
‘eco’	41 runs: 19.5 Wh/Gtkm	41 runs: 18.3 Wh/Gtkm
Biel - Zurich	**-3.4%**	***-7.4%***
‘baseline’	174 runs: 23.3 Wh/Gtkm	101 runs: 21.5 Wh/Gtkm
‘eco’	63 runs: 22.5 Wh/Gtkm	16 runs: 19.9 Wh/Gtkm

Note that the specific energy consumption is much higher for the segment Zurich-Biel (and vice versa) as compared to the specific energy consumption between Biel and Geneva (and vice versa). This is probably due to the high-speed segment (max. speed 200 km/h) between Solothurn and Olten.

3.3 Punctuality

While the tested system had no negative impact on punctuality, a more detailed look at the data produces a picture that is somewhat clearer.

In Switzerland, punctuality is measured based on a threshold of three minutes (in percent) on arrival at 53 major stations. As seen in Figure 5, the system compared to the baseline had no negative impact on this threshold of 180 seconds. Where it becomes more complicated is when we analyse the delay upon arrival between 0 and 60 seconds. The aim of the static speed profile is to use the running time margin in order to reduce energy consumption. In doing so, we expect to reduce the number of trains arriving at the stations early; this is clearly observable in the results. The discussion then turns towards what is acceptable within the timeframe of 0 to 60 seconds and if some trains should arrive slightly in advance by between -30 and 0 seconds. At the time of writing, discussions on this trade-off between punctuality and energy savings are still ongoing.

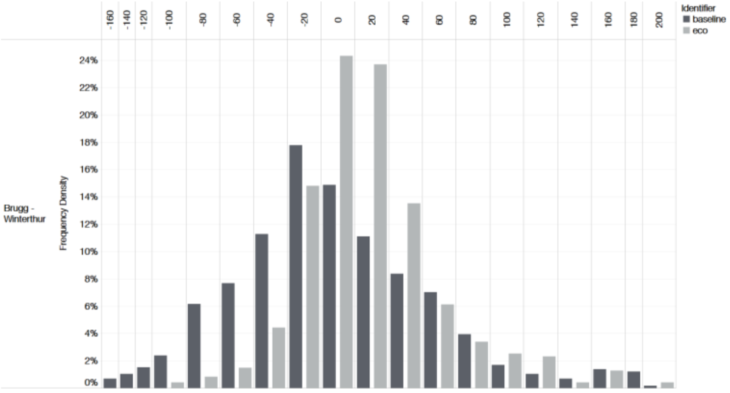


Figure 5: Histogram of delay upon arrival at fixed points for S12

Furthermore, for some test runs we measured an increase in arrivals with more than 60 seconds delay. These delays beyond 60 seconds are clearly not acceptable and we are analysing the reasons. An initial analysis of the causes of these delayed arrivals identified the following factors: driver difficulties in knowing the exact delay of the train at any time, which impacts on the ability to review the run strategy with respect to delay; some quality problems in running time calculations and a lack of margin to counterbalance train driver reaction times.

In summary, the comparison of the accompanied runs with the 'baseline' (same trains in the same period) shows a significant reduction in energy consumption achieved without affecting punctuality at 3 minutes: depending on the train run, the accompanied runs consumed between 1.4% and 13.3% less energy per gross tonne-kilometre. In general, the reduction on local trains is higher than on long-distance trains.

4 Discussion and Next Steps

Most of the train drivers were astonished to discover how well suited the speeds of the static speed profiles are and stated that the figures were confirmed in practice. Furthermore, following the eco speed profile is practicable and the modifications as shown in figure 4 are understood within a few minutes. These high levels of acceptance by train drivers combined with the significant reduction in energy consumption without affecting punctuality based on the three-minute criterion is promising. For this reason, a system-wide rollout scheduled for late 2019 is currently ongoing. The central topics for implementation in late 2019 are the automatic generation of fixed points, the trade-off solution for energy consumption vs. punctuality and the training of all train drivers in how to use the new system.

The implementation of this system represents a first step for the future development of the RCS ADL system towards ATO. It is also a component of the larger project smartrail (smartrail (2019)), which aims to reduce global system costs while increasing safety and capacity. The next step for reducing energy consumption on train runs will be the introduction of coasting speed profiles with future ATO systems. Furthermore, the smartrail project is also developing a new timetable planning system, which needs to factor energy-saving considerations into calculations for running times between fixed points, based on the work of Prof. T. Koseki (Koseki (2015)), to ensure the lowest possible energy consumption.

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