Evaluation of energy saving strategies in heavily used rail networks by implementing an integrated real-time rescheduling system

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Abstract

The Swiss Federal Railways in cooperation with the Swiss Federal Institute of Technology ETH has developed an integrated real-time rescheduling system to simultaneously improve rail network capacity and punctuality. The approach combines real-time rescheduling (performed after a delay or incident) with very precise train operation facilitated by providing dynamic schedule information to train drivers. This information enables train drivers to change their driving behaviour and adjust their speed based on the new schedule. This can significantly reduce the number of unnecessary decelerations or stops due to conflicts. Consequently, traffic flow is improved. In addition, also energy consumption is reduced because unintended re-accelerations are minimised. This paper describes results of an analysis performed to calculate the energy savings possible using the integrated real-time rescheduling system.
Keywords: rail traffic management; train dispatching; energy optimisation strategies.

1 Introduction

Railway operators have significantly increased passenger and freight service in the last several years. Consequently, railway infrastructure is being used more intensively and the system is becoming less stable. Under these conditions a small initial disturbance can propagate causing substantial knock-on delays throughout the entire network. In order to reduce the impact of these delays, train dispatchers must react quickly and make decisions based on current conditions. Given the complexity of this task, research on real-time rescheduling systems for rail networks has become an important research topic. Good overviews of the

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problem and potential solutions are described in D'Ariano [1] and Törnquist and Persson [2]. The focus for real-time rescheduling systems is to minimise knock-on delays by detecting and solving train conflicts quickly and thereby optimising usage of rail infrastructure. As real-time rescheduling systems are improved, the information they provide to dispatchers will change from simply detecting conflicts to proposing conflict solutions by re-ordering, re-routing and re-timing of trains based on train predictions and extended algorithms.

Another field of active research focuses on the optimal control of train operation (driving), see Albrecht [3], Franke et al. [4] or Howlett and Pudney [5] for more details. In this case, the optimisation objective is to minimise the train's energy consumption subject to physical (rolling stock and infrastructure) and temporal (timetable) constraints. Today, especially on heavily used railway networks, changing conditions and particularly delays cause trains to stop unnecessarily which wastes energy. Current state-of-the-art for energy optimal driving solutions are only effective for simple systems (e.g. static timetables), extending these systems to heavily utilised and heterogeneous rail systems will require developing dynamically changeable schedules in real time.

The Swiss Federal Railways (SBB) in cooperation with the Swiss Federal Institute of Technology (ETH) is implementing a new integrated real-time rescheduling system. The new system combines real-time rescheduling with continual provision of precise and up-to-date information to all affected actors (drivers, guard, infrastructure operators). The new system helps to improve service quality and capacity by reducing unnecessary signal stops. Since it reduces unnecessary stops it could also reduce energy consumption. This paper evaluates the energy savings possible using the integrated real-time rescheduling system with the support of micro-simulation and describes the main influence factors. Section 2 presents a short overview of the integrated real-time rescheduling system's structure and functionalities. Section 3 reviews results of earlier train energy saving research. Section 4 evaluates the energy savings possible using the integrated real-time rescheduling system and section 5 presents conclusions.

2 Integrated real-time rescheduling system

The main idea behind the SBB's integrated real-time rescheduling process is to continuously provide all actors with an up-to-date and conflict free schedule for all trains. This schedule would provide detailed information about time, speed and route (with an accuracy of seconds). The new approach combines two elements:

- Rescheduling trains in real-time after a disturbance, event, incident or delay;
- Controlling trains and infrastructure so that the dynamically calculated trajectories (new schedules) are followed with a predefined accuracy.

Figure 1 illustrates the proposed rescheduling system's structure and data flows.

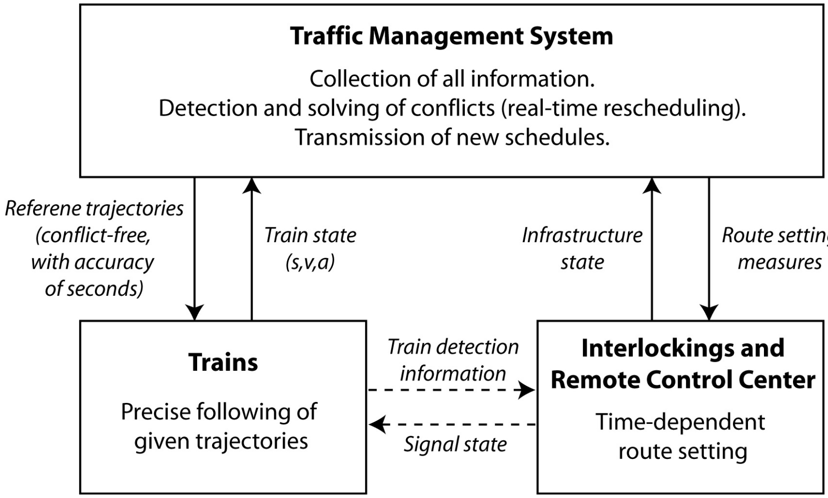

Figure 1: Integrated real-time rescheduling structure and data exchange.

One of the main problems in developing a real-time rescheduling system is that it must be both very fast and precise. The system must quickly identify any disturbance, deviation or event. Then it must immediately provide the event information (containing position, speed and state of train and infrastructure) to the traffic management system (and finally the rescheduling algorithm). This information must be as exact as possible to reduce the possibility that the system will make bad predictions and generate sub-optimal schedules. Next, the system must quickly provide the new schedule information to all necessary actors.

The rescheduling system uses two ideas to improve its overall accuracy. First, by communicating the new schedule information to train drivers it becomes possible for drivers to very precisely control their trains; this means that the rescheduling algorithm can safely predict when the train will arrive or pass specific points, which greatly increases the accuracy of the entire process. Second, by dividing the rail network into capacity bottleneck areas and links connecting them the process of generating a new schedule is simplified and speeded up [6].

One of the integrated real-time rescheduling system's most distinctive features is that it immediately communicates a dynamically changeable schedule to all actors including the train driver, guard and passengers. When this real-time schedule information is combined with a supporting assistant system such as a driver-machine-interface (see [7] for an example developed in the Netherlands) or used as input for an Automatic Train Operation (ATO) system, the schedule can be followed very precisely. Therefore, the timetable information or target trajectory, provided by the system to the drivers has an accuracy of seconds.

Recent improvements in communications technology have made it possible to quickly and accurately transfer information in both directions between the traffic management system and trains. Thus, train information such as state and position can be made available for the traffic management system almost immediately and train trajectories can be transmitted to drivers without delay. While the integrated real-time rescheduling system adds a significant level of control to train operations, it relies on the existing signalling and interlocking principles and infrastructure. A more detailed description of the integrated real-time rescheduling system and its benefits is presented in Laube et al. [8], Luethi et al. [9, 10] and Wuest [11].

3 Static energy optimisation

There is wide variation in the amount of energy a train needs to make a given trip. In 1999 and 2000, the SBB completed a set of tests on the line Zurich – Zug – Rotkreuz – Lucerne to identify key factors influencing the amount of energy needed and to assess various strategies for reducing energy demand [12]. These tests were carried out using IC-2000 intercity trains operated with a Re 460 locomotive and 10 wagons. The distance between Lucerne and Zurich is 57 kilometres, runtime is 48 minutes and there is only one significant grade with 13 per mill. The tests showed a large variation in the energy consumption and identified the following main influence factors:

- Runtime;
- Usage of electrical braking; and
- Number of unnecessary signal stops.

In addition to these main factors, weather conditions (adhesion) and train load were also found to influence energy consumption.

Figure 2 illustrates the influence of runtime on theoretical energy consumption for the track section between Lucerne and Zug. It shows that energy consumption is highest for trips with the minimal runtime (16.6 minutes) and that it decreases significantly with longer runtimes until runtime reaches a certain point (17.25 minutes), and then it continues to decrease although only slightly

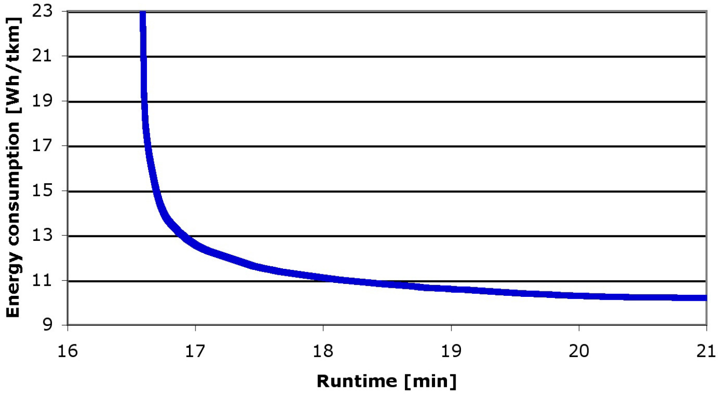

Figure 2: Minimal theoretical energy consumption depending on the runtime.

In addition to runtime, the train driver influences energy consumption through brake usage and the choice of brake used. The Re 460 locomotive has a powerful electric brake and a pneumatic disc brake where the entire kinetic energy is transferred into heat. Drivers were asked to use mainly the electric brake, but pneumatic brakes must be used when operating on minimal runtime schedules and making signal stops. The test runs showed that brake type has a significant impact on energy consumption. They also showed, using an elaborated optimisation algorithm, that it is possible to achieve energy savings of between 10 and 30% for traffic situations without unnecessary signal stops [4].

Algorithms and consequently train drivers are only able to minimise energy consumption when signals are open and the trains use the pre-planned track. Unexpected speed restrictions (e.g. due to changing a switch position) or closed signals force drivers to use the pneumatic brake thereby increasing energy consumption. The tests showed that energy consumption was approximately 10-15% higher for trains having an unnecessary signal stop than for unhindered runs. On track sections with capacity bottlenecks many trains are forced to make one or more unscheduled stops. For example over 50% of all IC-2000 trains from Zurich to Lucerne had to stop at Rotsee in the entrance area to Lucerne station (a major bottleneck) due to delays.

To summarise, the driving strategy (especially reducing unnecessary stops) significantly influences energy consumption and therefore offers a large saving potential. However, as the number of trains increases, the number of unnecessary stops due to delays also increases thus increasing energy use. As outlined in the following section, integrated real-time rescheduling can provide drivers with precise and up-to-date schedules that reduce unscheduled stops and thereby reduce energy consumption.

4 Energy optimisation with integrated real-time rescheduling

Railway traffic has grown significantly in the last several years; more trains are being operated often with no additional infrastructure. This situation increases the number of delays caused by train conflicts and also causes knock-on delays to propagate more quickly through the entire network. However, the new integrated real-time rescheduling system makes it possible to effectively implement measures such as re-routing, re-ordering and re-timing of trains thus minimising train conflicts and knock-on delays.

As outlined in chapter 2, the integrated real-time rescheduling system continuously provides train drivers with up-to-date driving trajectories enabling them to reduce unnecessary stops. The rescheduling system can use several different strategies and optimisation criteria in developing these new trajectories, including:

- Earliest arriving time;
- Minimal energy consumption; and
- Shortest blocking time.

In addition to these criteria, the topology, infrastructure, signalling and operation rules have significant impact on the final trajectory. Albrecht described the influence of these trajectories that anticipate train driving [13]. As outlined earlier, the precise trajectory strategy can be very effectively used before entering a bottleneck area. For example, the SBB has evaluated the strategy of slowing down and accelerating a train before reaching a capacity critical section so that the train passes through the bottleneck area with the maximum allowable speed. Figure 3 compares traditional train control to this type of dynamic train control using integrated real-time rescheduling. Figure 3 shows that the train with integrated real-time rescheduling arrives earlier in the station and uses less energy. The results show that the time difference can vary between several seconds up to several minutes depending on the train and infrastructure characteristics. The energy evaluation is based on braking and reacceleration – which provide more precise train control – rather than coasting to follow the train trajectory. However coasting could be added to the algorithms to further reduce energy use.

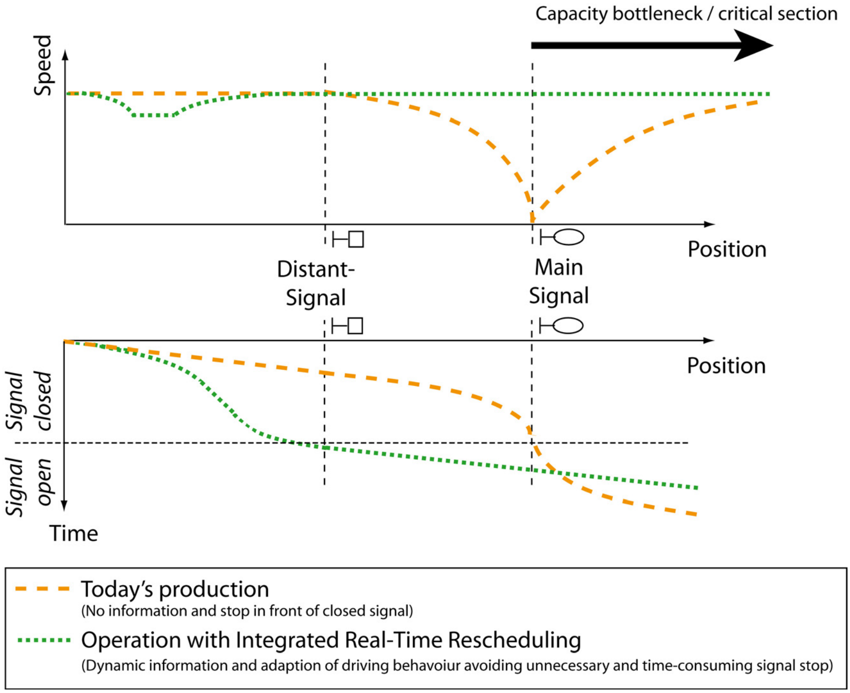

Figure 3: Comparison of traditional driving behaviour with speed control as part of integrated real-time rescheduling.

The goal of this research was to more precisely evaluate the impact of the integrated real-time rescheduling system (and in particular the point of time the new schedule is transmitted to the train) on energy consumption. The research used the OpenTrack train micro simulation application (see [14] for a description of OpenTrack). The evaluation considered the 18 kilometre track section from

Rotkreuz to Lucerne. This section includes a single line section starting at Rotsee (near Lucerne) which causes regular conflicts.

The research evaluated energy consumption based on when the train received the revised schedule. In all cases it was assumed that the train could enter the critical single line section exactly one minute later than originally scheduled (in other words the signal turned green one-minute later than scheduled). Of course, the earlier a new schedule is generated, the smoother or less deceleration and reacceleration is needed. The closer a train is to the critical point (Rotsee) when it receives the new schedule, the more energy it will use since the target speed (i.e. speed the train should be going to be one minute later) is lower (see Figure 4). This means that train operators must use pneumatic brakes since immediate and strong braking action is needed.

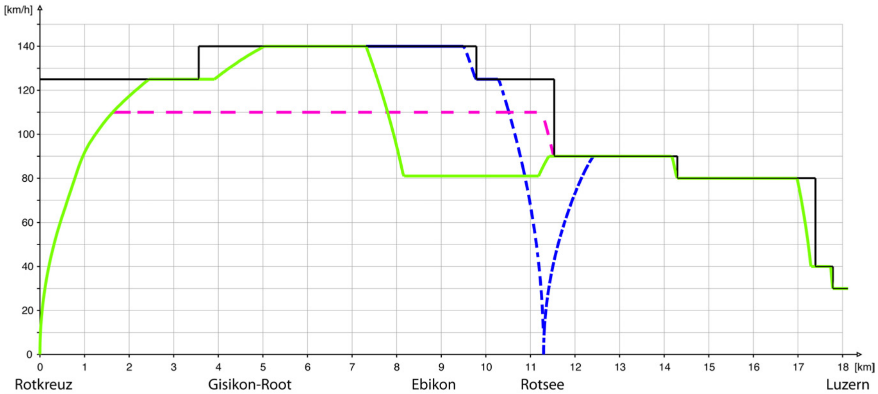

Figure 4: Possible rescheduling actions depending on the point of time rescheduling is executed resulting in identical arriving times in Lucerne.

Figure 5 illustrates the simulation results. It shows the minimal relative energy consumption depending on the point of time the rescheduling is executed (i.e. the new schedule is received and acted upon by the train driver). Figure 5 shows that for the first 100 seconds after departure from Rotkreuz, the relative energy consumption for all alternatives is minimal and identical. This is due to the fact that the train is accelerating to its target speed. When the rescheduling information is received between 125 and 160 seconds, the relative energy consumption increases, but remains approximately constant. During this period, the reduced target speed varies only marginally and the speed when rescheduling is executed is stable at 125 km/h.

When the rescheduling is executed between 160 and 200 seconds after departure from Rotkreuz, the train is in the process of accelerating up to the maximum line speed of 140 km/h and therefore relative energy consumption increases more or less linearly. Finally, when the rescheduling is executed between 200 and 310 seconds, the train must brake and slow down to a lower and lower speed resulting in a maximal relative energy consumption of up to 50%

higher than in the best case (early rescheduling). After 310 seconds, a full stop can not be avoided anymore.

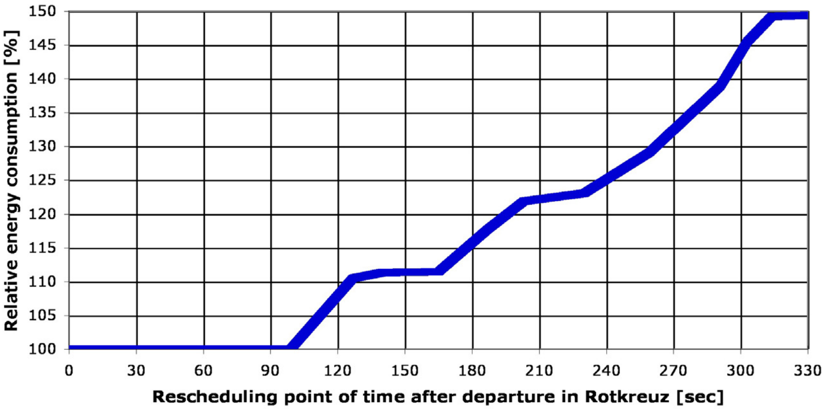

Figure 5: Influence of rescheduling point of time on relative energy consumption for the section Rotkreuz – Lucerne.

To summarise, the rescheduling point of time is a decisive variable in determining energy consumption. Providing precise train speed control information early enough so that drivers can reduce their need for braking and reacceleration to a minimum reduces energy consumption by up to 50%. The nearer to the critical point where rescheduling information is executed, the more energy will be consumed (since this requires strong braking and reacceleration). However, in all cases where a full stop can be avoided, rescheduling will reduce energy consumption.

Delays and blocked routes often occur in heavily used parts of the rail network and in bottlenecks where trains interfere with each other. A significant amount of energy could be saved in these areas by implementing integrated real-time rescheduling. As rail traffic increases, applying integrated real-time rescheduling systems is becoming increasingly necessary, not only to reduce knock-on delays, but also to save energy. To be most effective real-time rescheduling should be combined with energy efficient train control based on elaborated algorithms. Only the combination of both approaches will make it possible to fully achieve potential energy savings.

5 Conclusion

Railway companies are facing huge challenges, on the one hand demand is growing as concerns over sustainability, energy use and climate change become more significant, while on the other hand railways face increasing market pressure to reduce expenditures and capital costs. In short they must increase capacity and service quality at minimum cost.

Integrated real-time rescheduling systems are being developed to increase infrastructure capacity without making significant investments or causing more delays. An important element of these systems is providing train drivers with up-to-date data and new schedules. This enables drivers to precisely control speeds thus minimising unnecessary stops.

Unnecessary stops not only reduce network capacity and punctuality, but also increase energy consumption. Therefore, integrated real-time rescheduling systems that eliminate or reduce unnecessary stops can also reduce energy consumption. The research completed for this study showed that on the rail segment from Rotkreuz to Lucerne, energy consumption could be reduced by up to 50% with speed adjustments based on decisions of the integrated real-time rescheduling compared to traditional train control with a full stop and reacceleration. The research also showed that the point of time when rescheduling is executed is very important. Large savings are only achieved when rescheduling is executed early.

Real-time rescheduling should be combined with energy efficient train control to minimise energy consumption and achieve the largest possible energy savings.

References

[1] D'Ariano, A. Improving Real-Time Train Dispatching: Models, Algorithms and Applications, Trail thesis series, Delft, 2008.

[2] Törnquist, J., Persson, J. N-tracked railway traffic rescheduling during disturbances, Transportation Research Part B, **41(3)**, pp. 342–362, 2007.

[3] Albrecht, T. Ein Beitrag zur Nutzbarmachung Genetischer Algorithmen für die optimale Planung und Steuerung eines flexiblen Stadtschnellbetriebes, PhD Thesis, Dresden University of Technology, 2004.

[4] Franke, R., Meyer, M., Terwiesch, P. Optimal Control of the Driving of Trains, Automatisierungstechnik, **50(12)**, pp 606–613, 2002.

[5] Howlett, P.G., Pudney, P.J. Energy-efficient train control, Springer, Berlin, 1995.

[6] Caimi. G., Burkolter, D., Herrmann, T., Chudak, F., Laumanns, M. Design of a new railway scheduling model for dense services, Proc. of the 2nd International Seminar on Railway Operation Research, Hannover, 2007.

[7] Albrecht, T., van Luipen, J., Hansen, I.A., Weeda, A. Bessere Echtzeitinformationen für Triebfahrzeugführer und Fahrdienstleiter, Eisenbahningenieur, **58(6)**, pp.73–79, 2007.

[8] Laube, F., Roos, S., Wuest, R., Luethi, M., Weidmann, U. PULS 90 – Ein systemumfassender Ansatz zur Leistungssteigerung von Eisenbahnnetzen, Eisenbahntechnische Rundschau, **56(3)**, pp.104–107, 2007

[9] Luethi, M., Laube, F., Medeossi, G. Rescheduling and Train Control: A New Framework for Railroad Traffic Control in Heavily Used Networks, Proc. of the 86th Transportation Research, Washington DC, 2007.

[10] Luethi, M., Nash, A., Weidmann, U., Laube, F., Wuest, R. Increasing Railway Capacity and Reliability through Integrated Real-Time

Rescheduling, Proc. of the 11th World Conference of Transportation Research, Berkeley, 2007.
[11] Wuest, R. Dynamic Rescheduling based on Predefined Track Slots, Proc. of the 7th World Congress of Railroad Research, Montreal, 2006.
[12] Meyer, M., Roth, M., Schaller, B. Einfluss der Fahrweise und der Betriebssituation auf den Energieverbrauch von Reisezügen, Schweizer Eisenbahn-Revue, **22(8–9)**, pp 360–365, 2000.
[13] Albrecht, T. The influence of anticipating train driving on the dispatching process in railway conflict situations, Proc. of the 2nd International Seminar on Railway Operation Research, Hannover, 2007.
[14] Nash, A., Huerlimann, D. Railroad simulation using OpenTrack. Computers in Railways IX, eds. J. Allan, R.J. Hill, C.A. Brebbia, G. Sciutto, S. Sone, WIT Press, pp. 775–784, 2004.