OnTime – Network-wide Analysis of Timetable Stability

Burkhard Franke, Bernhard Seybold
trafIT solutions gmbh, Heinrichstr 48, 8005 Zürich, Switzerland
burkhard.franke@trafit.ch, bernhard.seybold@trafit.ch

Thorsten Büker
VIA Consulting & Development GmbH, Frankenberger Str. 30, 52066 Aachen, Germany
th.bueker@via-con.de

Thomas Graffagnino, Helga Labermeier
Swiss Federal Railways, Infrastructure, Timetable and Offer
Mittelstrasse 43, 3000 Bern 65, Switzerland
thomas.graffagnino@sbb.ch, helga.labermeier@sbb.ch

Abstract
OnTime is a simulation tool to assess the quality of timetables. In implementing a new approach to calculate delay propagation, new opportunities concerning the size of the area under investigation, the speed of analysis and the quality of results are achieved. This approach combines a macroscopic infrastructure modelling, a stochastic mapping of delay as cumulative distribution functions and the analytical calculation of delay propagation.

But this is not just yet another approach; OnTime is now in regular use in the planning process at Railway Infrastructure Managers in Switzerland and Belgium.

In this paper, we will point out the problems of assessing the timetable stability throughout different planning stages under field conditions and of realizing a software tool for the usage not only in academic but in a railway business environment. A short introduction in the basic concept of delay modelling and the calculation of delay propagation is followed by describing the implementation of railway`s requirements into an application. We demonstrate the consequences of calculating with distribution functions with reference to software design resulting in further performance gains by parallel computing. The short calculation times allow for new options when designing timetables. We give an outlook on new planning processes with short cycle times and on an iterative improvement process leading to better timetables.

Keywords
Timetable stability, delay propagation, punctuality prognosis, planning process

1 Introduction

The quality of the railway operation is an important factor for an efficient and successful railway system. Strangely enough, the quality of operation is hardly considered when designing the operation plan: the timetable. By stating this, we do not mean that no one cares about punctuality or the robustness of a timetable, but unlike demand forecasting, for which sophisticated models are used as a matter of course, there seems to be a lack of suitable methods and tools in a core area of railway operations.

Without a suitable approach, there is little information on stability risks when designing a timetable. A tool helping planners to improve timetables early enough has to meet at least the following terms:

- Significant and scientifically sound results forecasting the operational performance of the timetable, expressed by standard key figures
- Short calculation time for fast feedback on timetable quality
- Coping with varying levels of knowledge about infrastructure in short term and long term planning

This need triggered research work conducted at RWTH Aachen University from 2006 to 2011 (BÜKER [2]): The aim was to develop an approach giving fast feedback on timetable quality by a smart operation on random variables. The critical success factors proved to model and manipulate these random variables as cumulative distribution functions. The mapping of delay as distribution functions fits the stochastic nature of delays and the analytical calculation of delay propagation lead to a short calculation time.

Afterwards it proved possible to transfer this approach into an application: The tool “OnTime” [14] is available since summer 2011 and is currently licensed to Swiss Federal Railways (SBB) and Infrabel. They apply OnTime to assess the operating quality of timetable variants as well as to elaborate the impacts of particular changes in the timetable or incidents, e. g. temporary speed restrictions. The short computation time permits a more iterative improvement of timetables than it was previously possible.

In this paper, we will point out the difficulties of evaluating timetables during the planning process. After providing a general overview in Chapter 2, Chapter 3 gives a particular description of our approach. Today’s use of the approach is subject of Chapter 4 before various lessons learned for future applications are outlined in Chapter 5.

2 Ex-Ante Evaluation of Operational Key Indicators

The quality of operation is not only of high relevance in the eyes of railway customers but is without doubt a good measure for the quality of the railway system in general, too. Furthermore it indicates how good the timetable matches the infrastructure. But even more important than related figures for past days is the operational quality “ex ante”, as we could probably do something about it. The earlier a planner is able to identify stability risks when designing a timetable, the more options he or she has to improve the timetable, the infrastructure or the operation procedures.

Subsequently we use the term “stability” as the ability of the railway network to compensate for disturbances and return to the desired state. The stability of a timetable is an important attribute of a timetable’s quality; sadly it is quite hard to know in advance. In this Chapter we shortly explain the difficulties for assessing the timetable stability during the planning stage and draw some conclusions for a suitable stability prognosis.

2.1 Difficulties and Requirements for Improving Stability Evaluation

Evaluation of timetables generally faces a problem known as the planner’s dilemma: Decisions made in early planning stages have serious consequences on the quality of operation, but often these decisions are made with solely vague knowledge of the conditions of future operation. The more strategic the planning, the less constraints are known. Simulations based on the exact modelling of infrastructure fail to give advice as they cannot cope with vague input data. Variant decisions on timetable concepts, operating-process alterations or infrastructure development are, therefore, usually taken without considering their impact on future punctuality. This is quite unsatisfactory as those strategic decisions determine future operating quality to a great extent. Assessing annual timetables on the other hand is based on better information, but only small improvements of the timetable are possible until the day of operation. Being able to help with the improvement of timetables throughout different planning stages means dealing with different levels of data quality.

This gets more difficult when working on long term or strategic timetables: The infrastructure, vehicles and operation procedures are often part of the future to be designed. As an optimal combination of investments for a given service intention must be found, an iterative approach is often the best way to find the best variant. To support such an iterative optimization, a quality assessment should give fast feedback on how operation quality is affected. Fast feedback on quality issues generally helps in the development of timetables as it eases the improvement of planning.

Another issue is size and complexity of the considered network. Though it might be possible to assess the effects of single timetable alterations by expert planners or simple tools, the interdependencies of complex timetable changes in a national or international railway network need sophisticated support. Delay propagation due to train interaction might reach critical network segments and spoil an entire network, something that would be missed when inspecting only network segments. To get a true picture of the quality of a timetable, we must be able to consider the entire network including all interactions.

The requirements to evaluate timetable stability as stated above covers the flexible modelling of infrastructure, quick feedback and the ability to handle complex railway networks. But in order to give reliable results on timetable stability, we also need to pay attention to the process of delay calculation.

To be perfectly stable, a timetable has to compensate for at least all primary delays – everything that is caused by malfunctioning of facilities, operating resources or staff or to any other unscheduled events (e. g. signal faults, traction or brake faults, large numbers of passengers or boarding bicycles or personal damage). But as a timetable cannot be designed to cope with every single incident (margins compensating even a track closure would result in quite unattractive journey times), we are merely interested in an average level of disturbance. This average level of disturbance can be modelled as random variables, which reflects the stochastic nature of primary delays. Direct use of delay distribution in stability evaluation is preferred over calculations with different sets of singular delays as with "Monte-Carlo Simulations". The large number of calculations needed by the latter to realistically model the "background noise" of primary delay speaks against the aspired quick feedback. The next Chapter gives a short overview on those tools and other approaches.

2.2 Current Tools

The qualified assessment of the operating quality of timetables is mostly performed – if at all – with the aid of microscopic simulation. A variety of simulation system have established themselves in recent years, reference being made at this juncture to the RailSys® [17], OpenTrack [6] and LUKS® [7] systems.

Common to these methods is that they map disruptions by scattering in individual primary delays as deterministic variables. Obtaining statistically safe pronouncements on the behaviour of different timetable variants involves conducting a large number of simulation runs and pooling their deterministic results downstream ("Monte Carlo Simulation"). The large amount time needed to calculate and analyse a multiplicity of Monte-Carlo-Simulation handicaps the frequent and iterative optimization of operating concepts. The microscopic, i.e. very detailed modelling of infrastructure that the systems cited call for is suitable for observing infrastructural measures in small, limited areas of study. But the high effort needed for the build-up of a microscopic model restricts the use of microscopic simulations to infrequent investigations. The modelling of infrastructure and train movements on a microscopic level obstructs the possibility to assess the effects of train interaction in large, complex networks as these microscopic simulation tools can hardly cope with the large amount of data of nationwide timetables. Common to the systems mentioned is that they proceed either synchronously in discrete time steps (RailSys® and OpenTrack), asynchronously to reflect train priorities, or in an asynchronous/synchronous combination (LUKS®).

To cope with larger networks, some tools use a macroscopic modelling of infrastructure. Fasta [18] of the École Polytechnique Fédérale de Lausanne likewise adopts the principle of Monte Carlo simulation with a less exact mapping of infrastructure. The random aspect of train running is considered here in the form not of explicit primary delays but of stochastic running times. The Simone line of development [12] is similar as to infrastructure granularity and the Monte Carlo simulation principle.

The approaches referred to above share a trait whereby data on timetable stability, i.e. on the response of train operations to delays imported from outside, can only be obtained by assessing (arrival-) delays as a function of induced primary delays, i.e. indirectly. There is no direct measure of the stability of an operating concept.

Methods drawing on max-plus algebra (GOVERDE [1]) have resort to a mathematical equation for operational correlations and permit a – likewise indirect – assessment of timetable stability for each recurring time slice through evaluation of the critical path ("cycle time"). Their applicability is limited to clockface-pattern timetables.

2.3 Requirements to Overcome the Existing Shortcomings

The aforementioned tools all have different areas of application due to their features. A simple sketch of these areas of application is presented in the next figure. In addition, we give the scope of application for a new timetable evaluation tool as aimed for and later realized in the tool OnTime:

- It is intended to be capable of simulating up to entire networks but not achieving this on cost of an exact mapping of infrastructural and operational parameters. Though a microscopic infrastructure is out of reach, the tool should make use of the best information available. As the level of detail varies in different planning stages, a flexible way of dealing with input parameters is necessary.
- To get reliable results on stability, we object the Monte-Carlo approach, as this needs a very large number of simulation runs to generate statistically sound results. A methodology achieving reliable results in a much shorter time is needed for a quick feedback on timetable stability.

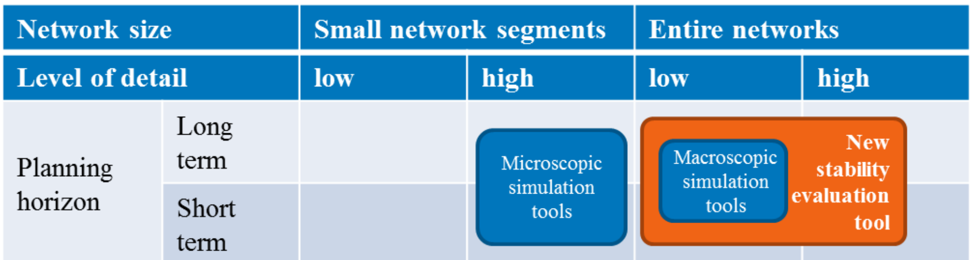

Figure 1: Area of application for a new stability evaluation tool

The needs sketched above were applied as basic principles while implementing the tool OnTime. Details on its realization are given in the subsequent Chapter.

3 Realization of the Application OnTime

The ideas behind the development of OnTime date back to the 1980s (WEIGAND [20]) and 1990 (MÜHLHANS [13]). Trials on forecasting the development of delay in an entire railway network led some important conclusions: to evaluate the principal design of a timetable and forecast its performance throughout a year of operation, this needs extremely high effort when applying singular disruptions like in Monte-Carlo simulations. Analysing the results of the multitude of simulation runs by statistical processing is another time-consuming procedure necessary to make use of the simulation results.

The main innovation was to turn the process upside down: not using lots of singular simulations and performing statistical analysis afterwards, but using distribution functions that fit the stochastic nature of delay. Consequently, every status of a train and their respective interactions has to be modelled by and calculated on cumulative distribution functions as well. This allows for a single calculation run to cover every possible situation in operation.

Research at RWTH Aachen University aimed at finding distribution functions that are suitable for railway needs at the one hand and practical for computational operation on the other (see Chapter 3.2). The first incarnation of a usable program for the evaluation of timetable punctuality and successful studies (WAAS [19], AKERMANN [1]) convinced SBB, Switzerland, and Infrabel, Belgium, to order the implementation of an improved quality assessment tool, later called OnTime. This order was assigned to the two companies employing the three authors.

3.1 Input and Output

OnTime was planned to fit into the planning environment of the different railway companies as an add-on to a planning tool. As such it has no own complex data management but gets all necessary data from the respective IT systems. The most important data are:

- timetable and operational information such as connections, train coupling and sharing or train priorities,
- infrastructure properties such as (minimum or operational) headways,
- primary and systematic delays.

The timetable file of every export format contains information about the used infrastructure of all the trains, therefore it is not necessary to keep an own data model of the infrastructure. This very much simplifies data handling, as there is no parallel maintenance of infrastructure models in a planning and a simulation tool. Only infrastructure properties have to be applied. This however has some drawbacks described in Chapter 5. Equally important is the correct differentiation of minimal process times (e. g. minimal running time) and the resulting reserve time in the timetable file.

The infrastructure properties can be applied efficiently by a rule-based system. By using this rule based system it is possible to start with default rules and sequentially refines these rules for specific infrastructure elements on demand. In doing so, the level of detail in infrastructure modelling depends only on the information given in the timetable. Therefore OnTime cannot be classified of being either microscopic or macroscopic; this depends on the granularity of the source of data.

Using the same rule-based system, it is possible to allocate primary delays. This allows the calibration of simulations down to the very detail.

Figure 2 shows the application window displaying the input files and settings on the left and a comprehensive view of a result's key figures on the right.

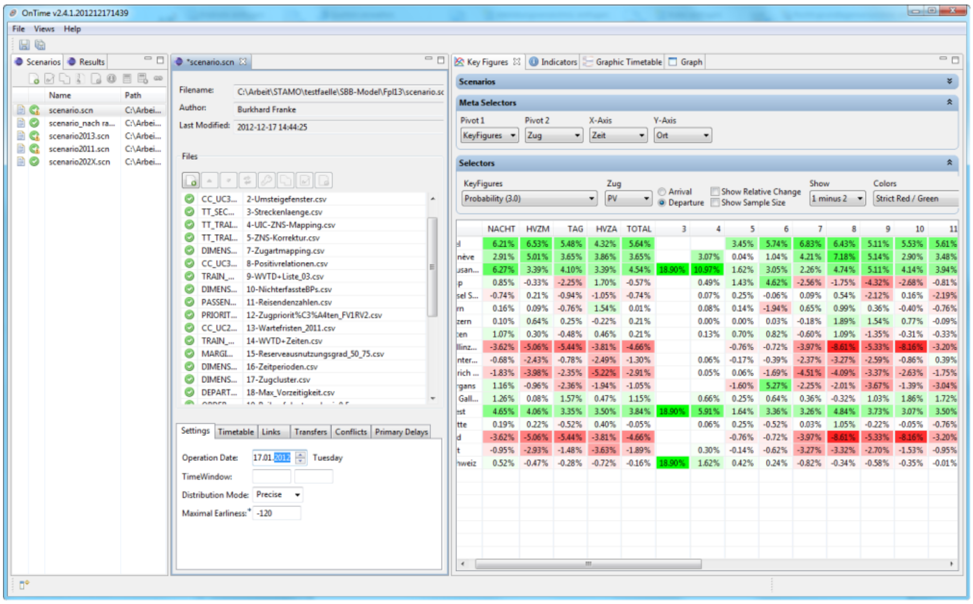

Figure 2: Application OnTime, displaying scenario files and results

Automatic aggregation of the key figures of the calculation results places the user in a position to speedily assess the results. It is possible to drill down data from a network-wide level to analysis by detail, such as train, station or time slice. As all delay results are present in form of distributions, the user can switch between the key figures of interest, expected delay, punctuality at various levels or quantiles for arrival or departure.

The network-wide results are great to get a first impression of overall timetable quality. For deeper inspection and to give planners a better view on what is happening, other ways of visualization are given at hand. Probably the most intuitive display of detailed results is the graphical timetable view (see Figure 3), as planners are used to this diagram in principle. Displayed are the trains as planned and their respective distribution of delay. The colour of the plot represents the probability of a train with the dotted lines representing the 5%, 25%, 50%, 75% and 95% quantiles. The example diagram shows the propagation of delay from a train with a broad distribution function (high spreading of delay) to a very punctual train when both trains meet at a crossing point of a single track line.

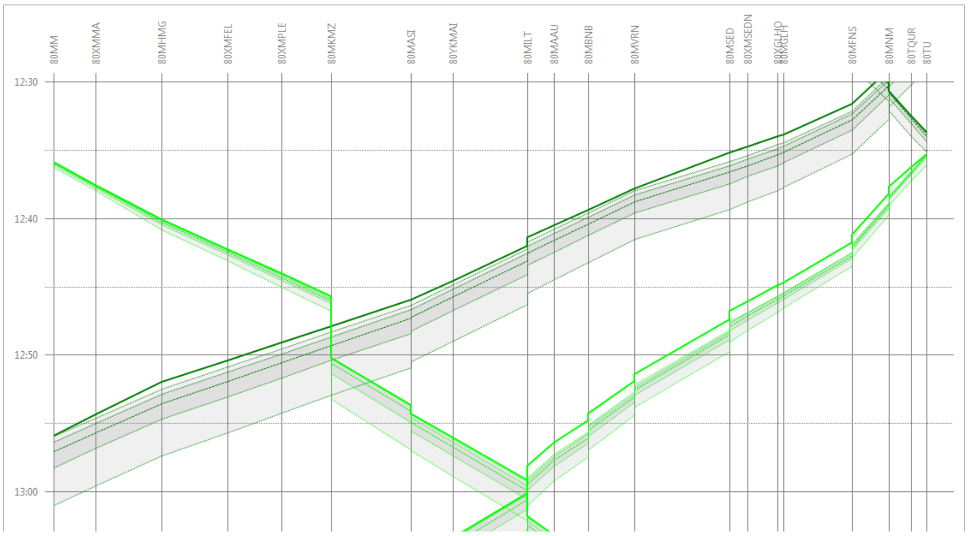

Figure 3: Graphical representation of results in a train diagram

Detailed results are also saved for further examination with specialized analysis software like OpenTimeTable of SBB or common spreadsheet applications. Figure 4 gives a brief illustration of input and output.

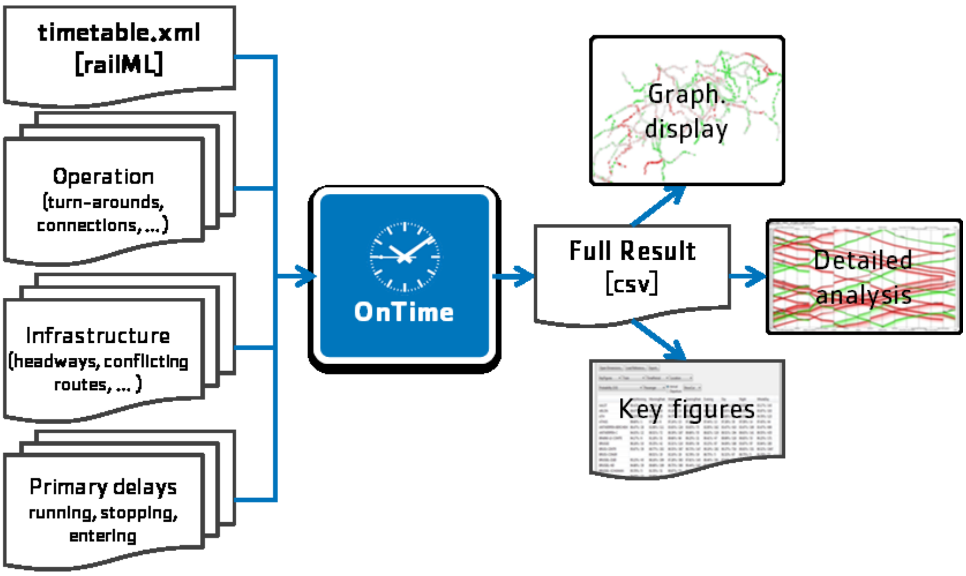

Figure 4: Data flow and result representation

3.2 Modelling of Delays and Underlying Calculation

Modelling and simulating the processes in railway operation by distribution functions is well accepted, see for instance KOLONKO [8]. There are some differences on the preferred class of distribution functions. The class of probability distribution functions needs to be selected for the modelling of delays that ensures a sufficiently exact adaptation to the real world whilst not leading to run-time and storage-space problems when performing computing operations. Existing modelling approaches either fail to embrace all requisite manipulations of random variables or else only permit approximate performance of these computing operations.

While some authors favour WEIBULL distributions; BÜKER [2] concluded that an extended exponential distribution fits best the practical use in railway operation modelling, as they best comply with the two main requirements:

- Mapping the status in railway operations correctly,
- Being suited for efficient mathematical operations.

The elaborated class of cumulative distribution functions serves to conduct the delay propagation by means of an activity graph.

The calculation itself covers a randomly selectable day of running and considers the entire spectrum of operating routines:

- Delay increase via primary delays during running and stopping and dispatching processes.
- Delay reduction by means of running and stopping-time recovery margins when establishing a maximum permissible negative delay on the line and during stops.
- Delay increase and reduction as a function of a given delay situation, meaning that, for instance, running-time recovery margins can be exploited differently for punctual or only slightly delayed trains than for trains that are considerably delayed.
- Delay propagation in the event of route conflicts, including change of sequence taking account of the applicable train priorities.
- Delay propagation caused by interlinking of trains due to turn-arounds, connections or train-coupling and -sharing.

In a first step of the calculation process, the activities of all trains and their interactions are created in a directed graph according to the timetable. This directed graph can also be used as a quality test, as potential conflicts are contained in this graph. The second step is the analytical calculation of delay increase or reduction and delay propagation.

The calculation may be performed in various degrees of precision representing differing levels of model simplification, with calculating times varying accordingly. A state-of-the-art software architecture and the use of parallel computation on multi-processor computers contribute to short calculation times as well (see Chapter 4.3). Therefore even large, complex networks can be analysed in a couple of minutes, and yet calculating times hardly exceed one hour on standard PCs even when the highest level of computing precision is used.

4 Usage

All ideas, approaches and tools finally have to stand the test of reality. OnTime successfully faced this test and made it into effective use as well at railways such as SBB and Infrabel as well as in consulting projects for the network-wide analysis of timetables.

4.1 Current Scope und Procedure of Studies

The scope of possible studies covers different planning contexts ranging from short-term to strategic planning. Set out below are a number of scenarios in which the methodology elaborated can yield value-added of practical relevance:

- A network-wide forecast of operating quality provides support for the assessment of timetable variants from the earliest planning phases. Extrapolating the consequences of anticipatable influences on operating quality allows the decisional base to be enhanced.
- Stability analysis augments the assessment of infrastructure projects by providing information on the resulting operating quality. It is also possible in the process to investigate network-wide consequences and interactions with other projects scheduled.
- Once an annual timetable (or a significant portion thereof) has been produced, a forecast of operating quality is made that is ideally factored into the target-definition process. This serves the purpose of assessing network-wide timetable stability under normal production conditions during compilation of the annual timetable. A forecast of this kind is of particular interest given changes in the service/rolling stock/infrastructure planning triangle.
- If there is some latitude regarding the allocation of recovery margins for a given train, an optimisation of distributing these recovery margins can be performed by iterative improvement. It is likewise of interest to pinpoint how the level of operating quality can be raised by modifying buffer times between trains.
- There are further scheduling checks and balances and operating procedures besides timetable modifications that impact on the resultant operating quality. These include maximum waiting times for ensuring service connections. A capacity for assessing and optimising such parameters in advance is of interest.
- The network-wide consequence of temporary speed restrictions is to be assessed. Gaining knowledge as regards the consequences of individual incidents is similarly of interest ("How long does the timetable need to recover from a single event?").

4.2 Daily Application

SBB as the first customer and development partner now has the broadest range of experience in using OnTime since 2011. Substantial effort was put into the calibration of the calculation: correct input data for primary delays were identified on the basis of detailed operational data (LABERMEIER [10] and iteratively refined by comparison to key performance indicators. With calculation results matching the real operational quality, the correctness of OnTime's methodology and implementation was verified.

Figure 5 gives some impressions on the quality of results achieved by SBB. The left side of the illustration shows real operational data of trains running in a major national corridor for a period of three weeks. The solid (black) line represents the scheduled train path, the thin lines represent real train runs and the dashed line corresponds to the resulting median. The left side of the illustration shows the corresponding simulation results as visualized in SBB's software solution OpenTimeTable. Even with a rather simple representation of primary delays as input parameters, the resulting trends of build-up and reduction of delays as well as the spectrums of trains - representing the deviation of delays – are considered to be good enough to map real operation.

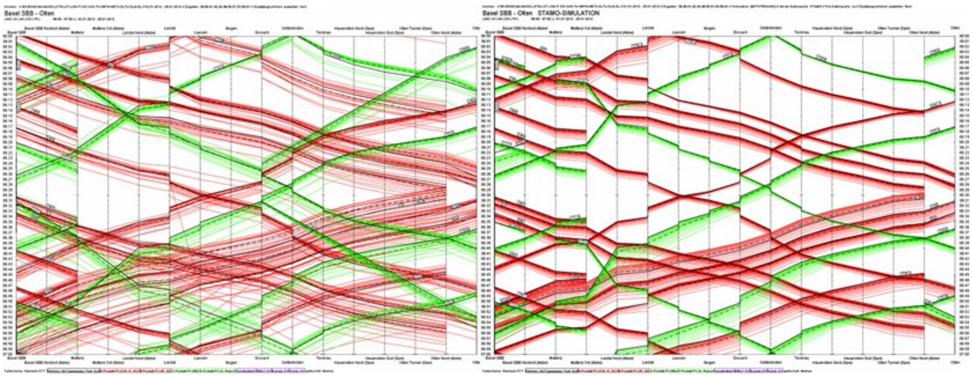

Figure 5: Comparitive display of real-time data and OnTime results

The application of OnTime at SBB currently covers:

- The regular evaluation of the new annual timetable to forecast the anticipated punctuality and to identify small improvements to the timetable.
- Assessing the impact on punctuality when adding extra trains to a given timetable.
- The evaluation of new timetable concepts in long term planning.
- Evaluating the effects of temporary speed restrictions due to construction works. The target is to support selecting an optimal combination of speed restriction per daily timetable along the annual timetable with a minimum impact on operation quality.

A second user, Infrabel ("toegang net" department), is configuring the model required to permit comparison of future timetable variants. Results are fed back to the timetable compilation to enable a continuous improvement. This is in particular of high interest, since the nationwide service scheme will be subject to major changes during the next years. In parallel, Infrabel follows innovative paths to determine the robustness of timetables by an iteratively modifying primary delays and evaluating the amount of caused secondary delays. Network-wide studies of both types will subsequently be augmented and intensified by the microscopic simulation of critical network areas with the simulation tool LUKS®.

Studies for DB Netz AG currently focus on strategic planning, analyzing the operational quality after implementing new timetable concepts on different future infrastructure scenarios. A lot of difficulties have to be solved as information on infrastructure and operation regime is often vague. In addition, the quality of the train planning is different from short-term – timetables, as it is mostly a planning draft with even multiple copies of individual trains in a data set (see 5.1). However, OnTime can deal with those timetable concepts and vague input data.

4.3 Performance

One of the main goals of OnTime was to speed up the process of timetable evaluation even for big networks. Short cycle times between timetable modification and evaluation very much ease the improvement of timetables. The components of an evaluation cycles are the preparation of calculations, the suitable processing of results and, most important, the calculation itself. The calculation time mainly depends on:

- Size of the network (number of operating points, number of trains)
- Quality of calculation (using simple or complex distribution functions)

- Level of detail of infrastructure modelling

To give an impression on the calculation time on a Laptop (2011, Core i7), some examples of real timetables and key figures are given:

Table 1: Calculation time

Network	# trains in calculation	Distribution mode	Level of detail	Time [min]
Switzerland, passenger trains	~8500	Simple	High	10
Switzerland, passenger trains	~8500	Precise	High	45
Belgium, passenger trains	~4000	Simple	Low	5
Belgium, passenger trains	~4000	Precise	Low	25
Germany, passenger and freight trains	~30.000	Simple	Low	15
Germany, passenger and freight trains	~30.000	Precise	Low	65

Calculation times of below one hour even for big networks allow a nearly iterative trial and error optimization of timetables. Calculation times benefit from parallel computing on multicore processors. The next figure shows the calculation time for a specific scenario with different processor settings and the single-core calculation set as reference. The speedup is smaller than expected theoretically due to e.g. overhead effects and as some I/O-processes are not parallelized at all.

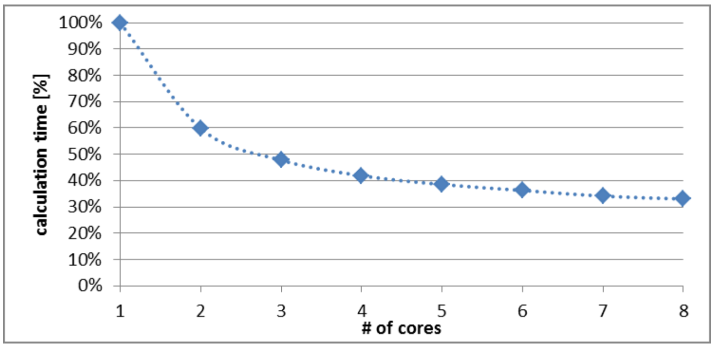

Figure 6: Calculation time depending on number of processing cores

5 Experience Gained and Outlook

Even before implementing OnTime, a lot of experience had been gathered by using the predecessor tool, other timetable evaluation tools and working in the timetables planning context in general. Still there were some surprises and technical findings we will share in this Chapter. Moreover, we give examples on the use of this approach in a related area in

Chapter 5.3 as well as some ideas for future improvements of the timetable planning process in general.

5.1 Dealing with Inconsistent Data

A lot was learnt when dealing with timetable files from different sources, i.e. different timetable planning programs. At first, OnTime was meant to trust the information from planning tools for granted, but this caused a lot of confusion. Depending on the nature of planning tool and the degree of permitted manual intervention, timetables needed editing.

Timetable planning programs permitting a lot of manual interference such as Viriato or, to a lesser degree ROMAN, accept even negative running and stopping times, not to mention conflicts between trains. We had to learn, that especially data of strategic timetables are often of dubious quality, but even the short term timetables (annual timetables of the upcoming timetable period) needed correction. To cope with timetable files of different quality, the data handling and delay propagation had to be upgraded:

- Preprocessing techniques to correct or manipulate stopping and running times. This makes it possible to correct i.e. stopping times, when only default stop times were set by planners without differentiation between minimal and reserve stop time.
- Applying probability to train paths. When planning catalogue train paths, not all of these train paths will be used by actual trains. Applying the idea of probability – which is part of the very idea of OnTime – at trains itself makes it possible to treat catalogue train paths correctly. It even makes it possible to ignore certain conflicts when some trains are not planned in detail: using a probability of 0.

5.2 Simplification of the Evaluation Process

The calibration of a simulation is often seen as a prerequisite for reliable results. In the introduction of OnTime at railway managers it was also needed to validate the tool and provide confidence in its results. Apart from the high effort needed to calibrate thoroughly, OnTime is meant to deal with future operation. There is a very high probability that input values describing operation in about 10 years' time based on different infrastructure will be different from today's calibration. Especially when doing comparative analysis on several alternative timetable or infrastructure variants, the first things we need to know is the relative performance of the variants. But does the result of such an analysis depend on calibration or is it even independent of input values? What level of quality do we need for the input parameters of a simulation?

To answer that, we will compare the statements of a calibrated simulation to a simulation using default parameters. As such research is currently under way; results will be presented at the railCopenhagen-conference. Understanding the influence of input parameters on the quality of results might simplify the preparation of simulations.

5.3 Application in Real Time Prognosis

Existing studies on connectional rescheduling generally envisage coupling microscopic conflict detection and resolution with macroscopic connectional rescheduling [9]. Delay propagation "beyond" the connecting services being rescheduled draws on a simplified continuation of delays either already existing or suffered due to connections being maintained. The basis for assessing rescheduling decisions could be enhanced by adopting the method for mapping delay propagation presented here beyond the horizon dealt with microscopically. Most notably, the short calculating time makes it possible to calculate and compare various connectional scenarios.

5.4 Teamwork with Automatic Timetable Generators

Despite a lot of effort by operation research scientists, timetabling is still mostly a labour-intensive work. An automatic generation of optimal timetables is not the usual procedure at today's railway systems; instead planners are solving conflicts between train path requests with only little help by their respective planning software. The Dutch system DONS was the only system used for the automatic generating of timetables of an entire network (SCHRIJVER et al. [16]) for a long time. Now new approaches seem to get closer to actual use (i.e. OPITZ [15], FORSGREN et al. [4]). Though widespread application of such timetable generators is still some time away, we would like to point out some aspects on the possibilities when using automatic generation of timetables.

Some authors aim at the single optimal timetable as the result of timetable generators (LIEBCHEN [11]). Practical experience shows that a working timetable is often found only by making compromises between the different aims e.g. minimizing consumption of resources, demand and stability.

In contrast, we propose an iterative step-by-step optimization of timetables with timetable generators producing several timetable variants. By evaluating the variants with specialized tools (like OnTime for timetable stability), promising variants can be identified and become the starting point of parameter variation in the timetable generator. Repeating this process iteratively leads to an iterative improvement of solutions. As the number of iterations per time determines the rate of improvement, the speed of evaluation becomes important.

Although this does not sound revolutionary in the first place, such an evolutionary approach to timetable design changes the process of timetabling from manufacture to an industrialized generation and optimization.

6 Summary

OnTime proved to be an appropriate tool for the quality assessment of timetables for real-world applications. Railway operators in Switzerland and Belgium use OnTime in the planning process for the evaluation and optimization of timetables. Both infrastructure managers are – as far as we know at the moment of writing – the only railways applying a regular quality test to new operating concepts and scenarios.

This was achieved by using suitable distribution functions for delay representation and calculation and a flexible representation of infrastructure attributes. The high speed of calculation lead to short feedback times for the evaluation of timetables. In conjunction with the possibility to assess entire networks this has the potential not only to improve timetables but also the process of designing timetables.

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