Delay Analysis of Rail 2000 1st Phase Using OpenTimeTable

Markus Ullius, SBB AG I-TM-PS

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Markus Ullius

SBB AG I-TM-PS

3000 Bern 65

Phone: +41 (0) 512 20 23 70

Fax: +41 (0) 512 20 23 02

email: markus.ullius@sbb.ch

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Abstract

To a degree seldom matched elsewhere, the current timetable of the Swiss Federal Railways (SBB) entails dense traffic at network nodes and track sections and complex national and international dependencies. Adding even more trains to the timetable could endanger its stability. Mitigating this danger requires additional means of analysis to locate and eliminate sources of disturbances.

OpenTimeTable is such an analytical tool. It uses operational data that is automatically captured on the SBB network. A wide-reaching analysis of this data can lead to better recognition of systematic delays and analysis of their context. The railway can use the resulting conclusions both in the short term (within the current timetable period) for measures relating to operations and in the longer term (for later timetable periods) for timetable optimization. In both cases, the changes can improve the quality of operations and thus form the basis for an optimal network load with a high degree of punctuality.

The first part of this paper describes OpenTimeTable's CorridorAnalyzer and NetAnalyzer that provide a variety of functions to analyze how a timetable performed during a certain time period. The second part describes how OpenTimeTable was used to analyze the new timetable for Rail 2000 1st phase that went into action on December 12th 2004 and presents some first results on how the new timetable performs.
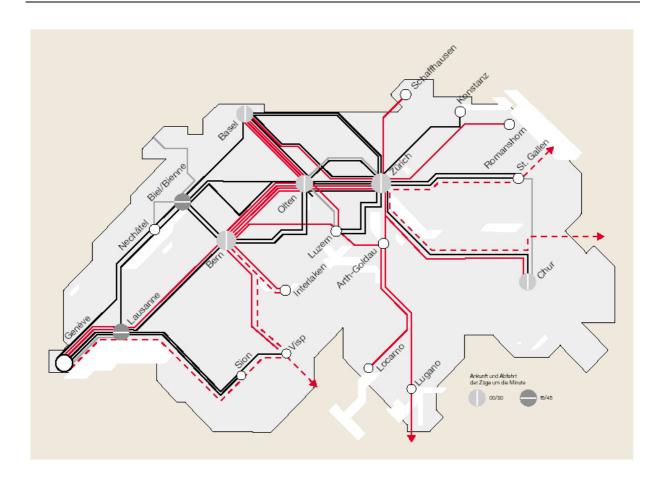
Keywords

Railway scheduling - schedule data analysis - timetable development - timetable quality evaluation - Rail 2000

1. Introduction

In 1987 Swiss citizens voted for the concept Rail 2000 having the goals of "more frequent, faster, more direct and more comfortable services". These catchwords are translated into practice by shorter travel times, better connections in the hubs and the half-hour cadence of train services in long-distance traffic.

To achieve these goals a sophisticated hub system of trains serving the stations always at the same minute every hour or half hour forms the basis for a better accessibility of all regions of the country. At the hub stations the trains and buses arrive either shortly before the full or half hour (or at the minutes 15 and 45) and leave shortly afterwards (see figure 1). The ideal connections contribute to making the travel times shorter.

Figure 1   On December 12th 2004 the new timetable of the first phase of Rail 2000 went into service. 90% of the trains have a new schedule and the average train-kilometers per day are stepped up by 14 percent to reach a total of 337'000 kilometers

Source: SBB AG – Internet.

Since Swiss people has spent CHF 5.4 billion for the 1st phase of Rail 2000 there was a big political pressure on SBB to make the new timetable work without major problems. In the months and weeks before December 12th the press often reported about the big project. On the core part of Rail 2000 – the 45 km long "Neubaustrecke" between Mattstetten und Rothrist - it was intended to use ETCS to allow speeds of more than 160 km/h. ETCS transmits the orders to the drivers directly onto a screen in the locomotive cabin. Because of technical problems during the development of the ETCS, SBB decided in December 2002 to install conventional signals on the "Neubaustrecke" as a fallback level in signalling. Since the ETCS was not ready to use for the 1st phase of Rail 2000 the new timetable has to be realized by using the conventional signalling allowing only 160 km/h instead of 200 km/h as it was planned. This means 2-3 minutes less buffering times in the timetable to reduce potential delays.

2.   OpenTimeTable

OpenTimeTable is a computer program designed to analyze actual timetable data to improve the quality of railroad schedules. It helps users evaluate and understand the huge amount of actual schedule data by presenting a variety of graphical and statistical data for selected groups of trains on particular corridors. By providing schedule planners with a complete understanding of systematic schedule delays, it helps them produce better schedules.

Development of OpenTimeTable has started in 1998 at the Swiss Federal Institute of Technology's Institute for Transportation Planning and Systems in cooperation with the SBB and now development is continued at SBB.

OpenTimeTable consists of two independent parts – the NetAnalyzer for net wide automatic analyses and the CorridorAnalyzer to analyze a corridor in detail. A description of those parts can be found below.

2.1   Input Data

The basic input data for OpenTimeTable are continuous train-position records stored by information systems at train control centers (e.g. system SURF at SBB). The first step in preparing an OpenTimeTable analysis is to import the train position data from the railroad company database into the OpenTimeTable database.

Train position records contain data about each train operation through a time point (a time point is a specific location on the track network where data is collected such as a signal location). The combination of data for a consecutive set of time points consists of a train operation (or "running"). Train position records consist of:

- Train identification number;

- Day of operation;

- Arrival time at time point;

- Arrival delay (number of seconds that the train was late or early arriving at the time point);

- Departure time from time point;

- Departure delay (number of seconds that train was late or early leaving the time point).

OpenTimeTable imports this train position data in form of ASCII-files and stores it in an own SQL database for further evaluation

2.2 CorridorAnalyzer

The CorridorAnalyzer is a classical desktop application and has three main function categories as described in the next subsections: The graphical timetable, the delay distribution and the capacity distribution.

At this point it has to be remarked that OpenTimeTable can only analyze data – the user has to make the conclusions from these analyses. To do this he often has to take additional data sources into account like delay causes.
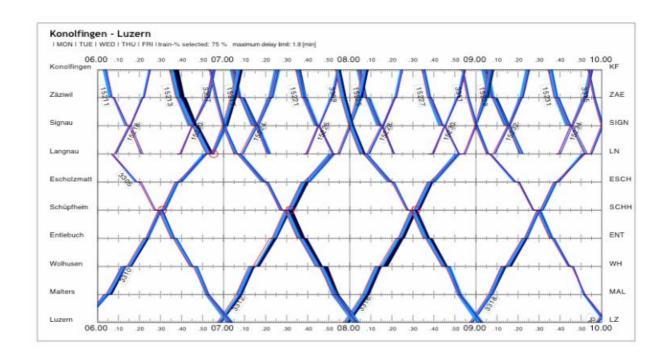
2.2.1 Graphical timetable

The graphical timetable is the CorridorAnalyzer's core module. A graphical timetable is a type of time-space diagram. It presents a graphical description of motion of a vehicle (in this case a train) over a specified time and space. The user can define a corridor, the date period and the trains he's interested in. As a result he gets a graphical timetable showing the single train runnings, the mean and median running calculated from the delays, the standard deviation of the delays, a percentual cover area and dwell times exceeding a user-defined limit.

Percentual covers are used to indicate the band of time when trains occupy a given section of track. They are displayed based on a user-defined variable. Users can set covers for any percentage of trains. By defining a maximal tolerated limit, parts of the percentual covers exceeding this limit are shown in a different color.

There are a lot of functions available to select and deselect trains and days by giving some criteria like "select all trains running from station A to station B having anywhere a mean delay of more than 3 minutes"

Figure 2   In this example the cover illustrates that the first 75% of all trains in the analysis group occupy this section of track during the time covered by the band. The black area indicates delays longer than 1.9 minutes.
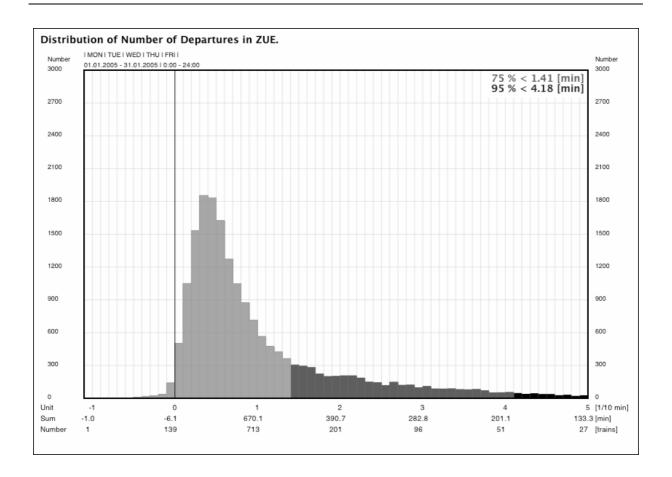

Source: SBB AG – OpenTimeTable CorridorAnalyzer.

2.2.2   Delay distribution

A delay distribution shows the number of trains in the observation period in various delay groups. Delay distributions are prepared for a particular time point (generally a station) or set of time points. Figure 3 illustrates a delay distribution on working days for all passenger trains at Zurich during the entire day between January 1st and January 31st 2005.

In addition to the graphical representation, the delay distribution diagram also presents statistical data for the selected train group. Thus, the figure presents the time when 75% and 95% of the trains have departed (in less than 1.41 and 4.18 minutes) in the upper right part.

Besides the delay distribution, also the delays per hour of day, per weekday, per week of year and per month can be displayed.
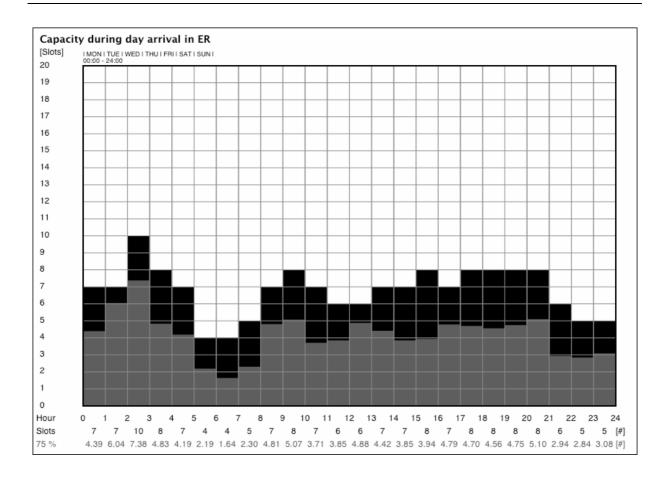
Figure 3   This example shows the number of trains departing during each 1/10-minute
time-interval from 1 minute early until 5 minutes late in January 2005 at Zurich. The figure's
black vertical line (at x = 0) shows the scheduled arrival time. The delay distribution figure can
be colored to illustrate various percentages of train arrival times. In this example the light gray
area is used to illustrate when the first 75% of trains have departed (in this case within 1.41
minutes of scheduled).

Source: SBB AG – OpenTimeTable CorridorAnalyzer.

2.2.3   Capacity distribution

The third type of graphical analysis that can be prepared using the CorridorAnalyzer is a
capacity distribution diagram. The capacity distribution is a histogram that plots the number
of observed events that take place in a given time period. In the case of a capacity distribution
the events of interest are arrivals at a station, or occupancies of a given section of track.
Capacity distributions help planners analyze the effective use of railway infrastructure time-
slots.

Figure 4   This figure presents an example of a capacity distribution diagram for Erstfeld (ER). It shows how many trains have been operated through the station during a 24-hour period. As with the CorridorAnalyzer's other graphical representations the analysis module presents summary statistics and allows users to set covers to display percentage points (e.g. 75% of trains are accounted for in this number of observations).

Source: SBB AG – OpenTimeTable CorridorAnalyzer.

2.3   NetAnalyzer

To avoid the necessity to know where a potential problem is located on the net the NetAnalyzer tries to give the user hints about problematic trains by analyzing data automatically on the whole net or on a subnet. To reduce the amount of data and calculation times the NetAnalyzer allows the user to create a subnet by defining corridors and train groups.

At the moment of writing this paper the NetAnalyzer has 4 main function groups as described in the next subsections.

The NetAnalyzer is a web application based on Apple's WebObjects technology.

2.3.1 Trains having too much delay

This kind of analysis reports all trains exceeding a delay limit over a given frequency during a user defined time period. Example: Report all trains having a delay longer than 3 minutes in more than 30% of the runnings during the last 30 days.

This calculation is executed every day after importing data and the trains not meeting the requirement are reported to the user as shown in figure 5.

Figure 5   Example report for train 566 being more than 3 minutes late in 60% of all runnings (12 of 20 times) in the current time frame of 28 days. Since the weekends are not included in this example there are less than 28 runnings in the 28-day-window. At Landquart all 20 runnings had a mean delay of 2.9 minutes. The 12 runnings not meeting the requirement had a mean delay of 4.1 minutes.

Train Report of *3.2.2005 Train: 566* | *2* records found.

Show all trains | Show plots

previous day | previous week   2005-02-03 [↕] (go)   next day | next week

Trainnr	Stations	Percent	#>Limit	Avg All	Avg Delay	Median Delay	Max Delay	Quality Level
566	Landquart ab	60 %	12 of 20	2.9	4.1	3.3	6.1	3.0 min. 60 % 28 days
566	Sargans an	60 %	12 of 20	3.1	4.2	3.2	5.9	3.0 min. 60 % 28 days

previous day | previous week   2005-02-03 [↕] (go)   next day | next week
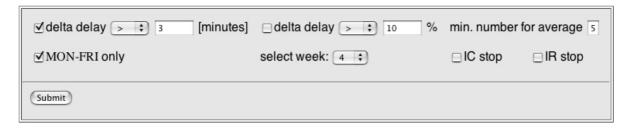
Source: SBB AG – OpenTimeTable NetAnalyzer.

2.3.2 Weekly delay comparison

This analysis compares the mean delays of one week with the corresponding mean delays of its predecessor. The mean delays are calculated for each train and station. The user has the possibility to define search criteria like "all trains having an increase of the mean delays of more than 3 minutes". The comparison can focus on trains, stations or trains and stations.

Figure 6   This example shows the comparison of the mean delays between week 3 and week 4. Train 17107 had an increase of the mean delay of 6.5 minutes.

Weekly comparison for all trains: *178 records found*.

Delays more than 10 minutes early or more than 20 minutes late are not included in the calculation!

☑ delta delay > ÷ 3   [minutes] ☐ delta delay > ÷ 10   % min. number for average 5

☑ MON-FRI only   select week: 4 ÷   ☐ IC stop   ☐ IR stop

(Submit)

show station summary

TRAIN SUMMARY	week 3 2005-01-10 - 2005-01-14	week 4 2005-01-17 - 2005-01-21	Delta
Train	Avg Delay [min]	Avg Delay [min]	Avg Delta Delay [min]
17107	-3.77	2.73	6.50
15124	2.70	8.87	6.17
17320	1.39	7.28	5.89

Source: SBB AG – OpenTimeTable NetAnalyzer.

2.3.3   Development of percentage delay

To check the given quality specifications (75% of the trains have less than 2 minutes of delay and 95% of the trains have less than 5 minutes of delay) the maximal delays for these percentage values are calculated for each station and day. This module provides a way to analyze the development of those quality criteria over time for each station.

Figure 7   This example shows the percentual maximum departure delays at Zurich main station for each day. On February 3rd the best 75% of the trains departed with a delay of less than 1.3 minutes.

Percentual delay development: *75 % have 55 records, 95 % have 55 records.*

Show data for: [Zürich PB ab ▲▼]
☐ create file for download: (Submit)

Percentage delays for: 75 %

Zürich PB ab	Delay [minutes]		
Date	Median	Mean	Max
2005-02-03	0.48	0.51	1.30
2005-02-02	0.60	0.70	1.89
2005-02-01	0.57	0.66	1.82
2005-01-31	0.48	0.54	1.44
2005-01-30	0.44	0.47	1.57
2005-01-29	0.47	0.48	1.17

Percentage delays for: 95 %

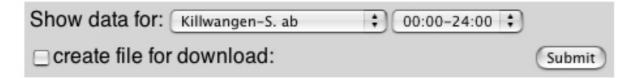| Zürich PB ab	Delay [minutes]		
Date	Median	Mean	Max
2005-02-03	0.60	0.85	3.62
2005-02-02	0.78	1.18	5.20
2005-02-01	0.72	1.10	4.27
2005-01-31	0.63	0.93	3.89
2005-01-30	0.55	0.99	4.28
2005-01-29	0.58	0.83	4.08

Source: SBB AG – OpenTimeTable NetAnalyzer.

2.3.4   Development of capacity usage

This module determines for each day the number of passenger- and cargo trains passing at a station to analyze the used capacity and it's development. It also shows the percentual value of passenger trains compared to cargo trains.

Figure 8   This figure shows how many slots were used by passenger trains and cargo trains at Killwangen during the whole day.

Capacity comparison: *51 records*.

Show data for: [Killwangen–S. ab ⬍] [00:00–24:00 ⬍]

☐ create file for download: (Submit)

Killwangen-S. ab	Number of trains		Percentage value	
Date	Passenger	Cargo	% P	%C
2005-02-03	472	247	65.65	34.35
2005-02-02	489	262	65.11	34.89
2005-02-01	483	263	64.75	35.25
2005-01-29	457	70	86.72	13.28
2005-01-28	490	248	66.40	33.60
2005-01-26	483	261	64.92	35.08
2005-01-25	493	286	63.29	36.71
2005-01-24	496	229	68.41	31.59

Source: SBB AG – OpenTimeTable NetAnalyzer.

3.   Analysis of Rail 2000 1st phase

Regarding Rail 2000 1st phase the most important point was to determine as fast as possible if the new timetable contains any conflicts as a result of planning mistakes, if the given requirements of punctuality can be met and how punctuality of the new timetable compares with the punctuality of the old one.

This chapter describes how the timetable department (I-TM-FP) has handled these topics in a more detailed way.

As measure of quality SBB defines the following criteria in the arrival of passenger trains:

- 75 % of the trains are delayed less than 2 minutes

- 95 % of the trains are delayed less than 5 minutes

3.1   First results

During the first week after December 12th the timetable department (I-TM-FP) has analyzed the trains every day by plotting out the graphical timetable (planned and daily train runnings) for each line (about 30 lines) of the net and looking at all trains that were delayed. Each plot is about 1.8 meters long and about 40 centimetres wide. To have an overview all plots were pinned side by side at a wall. Delayed trains were marked on the plot and their delay cause has been verified looking it up in the system ErZu (Ereignisse im Zugsverkehr, events in railway traffic). At the train control centres trains having more than 3 minutes of delay have to be registered in the ErZu-System.
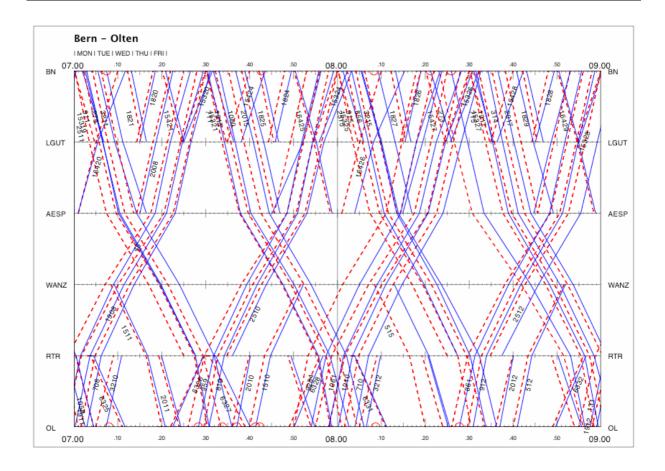
After the first week the timetable department concentrated this kind of daily analyses on looking at the mean values instead of the single train runnings (see figure 9). Since end of December analyses are made once per week and special reports are created on demand.

Besides the graphical timetable also the distributions of the train delays in 10 important stations were analyzed in detail and compared to the old timetable's distributions of the delays. To check the defined quality criteria of 75 % and 95 % the maximum delays for those values were determined from the delay distribution and also compared to the corresponding values of the old timetable (see figure 10).

To analyze realized capacities (mainly for cargo trains) the traffic at 10 points on the net is looked at using the NetAnalyzer and the CorridorAnalyzer's capacity distribution (see figure 4 and figure 8)
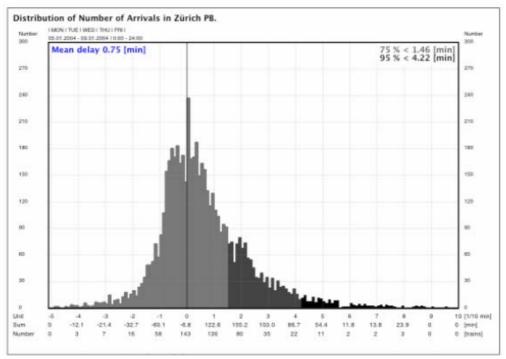
SBB also created an inter division (infrastructure and operators) traffic management task force (VMZ, Verkehrs Management Zentrale) collecting messages and data to eliminate systematic sources of delay, to work out a list of problems to solve and to create reports for internal and external communications. This list of problems includes overcrowded trains, conflicts between trains, trains having too weak engines and so on. On January 20th 2005 331 tasks out of 426 could be resolved. The other tasks were in progress or needed further observation. In it's reporting the VMZ also included the delay distributions made with OpenTimeTable's CorridorAnalyzer (see figure 10).
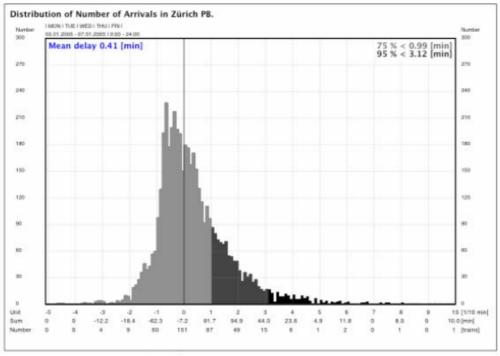
Figure 9   Example of a graphical timetable between Bern and Olten via the 45 km long "Neubaustrecke" between Mattstetten und Rothrist. The dotted lines indicate the planned timetable; the other lines show the mean realized timetable between December 13th 2004 and December 17th 2004.

Source: SBB AG – OpenTimeTable CorridorAnalyzer.

Figure 10   Distribution of arrival delays from January 3rd 2005 to January 7th 2005 for all
trains at Zurich (below) compared to the corresponding distribution between January 5th 2004 –
January 9th 2004 (above). This example shows a better punctuality of the new timetable in
Zurich.

Source: SBB AG – OpenTimeTable CorridorAnalyzer.

To inform customers about the new timetable SBB started a big public relation campaign weeks before the timetable change. Thanks to this campaign most people knew about the change of timetable and found their new trains. During the first few days more than 2000 additional SBB employees from every part of the company were at the stations and platforms to help customers finding their new trains and to support if there should be any problem.

One difficulty was to predict which train passengers would take when the departure time changes. Will they take the earlier train or the later one? So, in the first weeks there were some overcrowded trains until it was clear, which trains need more wagons.

4. Results

Even having more trains on the network the new timetable performs better than the old one. A reason for this is the fact that the new timetable was created from scratch whereas the old timetable was a patchwork created over the past several years.

In the area of national cargo trains first analyses have shown that even having more passenger trains on the net punctuality is about the same and in certain areas even better as in the old timetable still having about the same amount of cargo trains.

Evaluations of ErZu's delay causes between January 1st 2005 and February 6th 2005 show that most delays come from abroad or other infrastructure companies, followed by failures of the safety level and defective rolling stock. Only a small fraction of the delays come from errors in the timetable (as shown in table 1).

Since 90% of the trains have a new timetable also methods to measure passenger's count and kilometres had to be changed. Since December 12th passenger's numbers were taken in the 5 largest hubs (Zurich, Bern, Lausanne, Basel and Lucerne). First results (after a month) indicate a passenger's gain of about 3 to 4 percent (Weibel [5]).

One big problem after the timetable's change was the new S-Bahn in the region of Zug with its new stations. There were many problems of punctuality and customer information. The reason was the new rolling stock on which the new timetable was based on, was not available at that time. And in addition to this also a new customer information system having some early adopter's problems was introduced. Because of this accumulation of risks, which is normally avoided, the start of the new S-Bahn was not like desired but it was not a problem of an error in the timetable.

Table 1   Delay causes

Rank	%	Delay cause	Delay
1	29.24	Delay from abroad or from other infrastructure companies	132'318 min
2	13.79	Safety installation	62'392 min
3	11.43	Defective locomotive	51'735 min
4	7.34	Defective wagons	33'203 min
…			
26	0.16	Timetable	716 min

Source: SBB AG – ErZu.

5. Conclusions

The railroad industry is in the midst of great change. Railroads are being forced through government mandate and, more importantly, by customers, to provide better service and to be more efficient. Today's railroads must provide more and better service often with fewer resources. The key to succeeding in this new world is very careful planning and scheduling – focusing on getting as much out of the existing network as possible.

OpenTimeTable is one of a series of computer programs being developed to help railroad planners in this effort. It allows users to compare actual schedule adherence data with schedule timetables in a variety of graphical displays and statistical outputs. This information can then be used by schedule planners to help determine the cause of schedule problems and to develop solutions for these problems.

Regarding Rail 2000 1st phase the most important point was to determine as fast as possible if the new timetable contains any conflicts as a result of planning mistakes. Using OpenTimeTable this job could be done in a very short time. After the big part of the cargo trains joined the passenger trains on Tuesday, December 14th without any serious problems it was clear that the new timetable works and the delays were caused mostly by technical problems.

Even having a timetable without any major problems it has always to be kept in mind that in such a complex and heavily used railway network a trouble at the wrong place can cause long delays or even a disruption of parts of the net – as a computer crash in February 2005 at Zurich's main signalling box has shown. For this reason a good strategy of trouble shooting and customer information policy are very important.

As shown in the ranking of delay causes in table 1 a reduction of technical troubles and delays of trains coming from abroad can significantly improve timetable's quality.

To keep the timetable stable SBB has a rigid policy providing connections for delayed trains but in this case passengers don't have to wait too long for the next train.

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