

Understanding the Timetable Planning Process as a Closed Control Loop

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Abstract

This paper describes how the combined use of OpenTimeTable, a schedule analysis program, and OpenTrack, a railroad network simulation program, can be used to help develop more robust timetables. The paper describes how these programs and additional statistical analysis was used to help identify causes of delay and evaluate solutions for reducing this delay on Zurich's suburban rail network. OpenTimeTable was used to identify trains susceptible to delays, as well as network bottlenecks and conflict points using actual operating data. Results of this analysis were then used in OpenTrack to complete a microscopic simulation of the network to understand and visualize the dependencies and delay patterns. The paper describes both the OpenTimeTable and OpenTrack programs in detail. Finally, the paper suggests that using a Web Services approach to combining the existing analysis and network simulation applications with a schedule optimization program through RailML based data transfers might be the most efficient way to automate the railroad schedule development process and lead to improved railroad schedules.

Keywords

Timetable planning process, Railroad scheduling, Railway simulation

1 Introduction

Railroad network capacity, schedule stability and journey time represent a closed unit; in other words attempting to optimize one of these parameters often causes a deterioration in the others. In order to reduce these dependencies and to increase the timetable robustness, delay prone parts of the network – these could be either capacity critical nodes or blocks – must be identified through the process of analyzing actual (or simulated) operating data. Once these problems are identified, they can serve as new constraints for developing the next timetable and can be re-analyzed, repeating the process. As this description shows, the schedule planning process can be understood as a closed control loop.

2 Analytical Delay Pattern Recognition

2.1 OpenTimeTable

OpenTimeTable [5,7] is a computer program designed to analyze actual (or simulated) train operating data from a given network. OpenTimeTable allows users to edit data and

make it available in a wide variety of graphical displays and statistical outputs. This helps railroad schedule planners evaluate and improve the quality of railroad timetables. The tool is especially helpful in recognizing systematic schedule delays so that they can be eliminated from the next planned timetable.

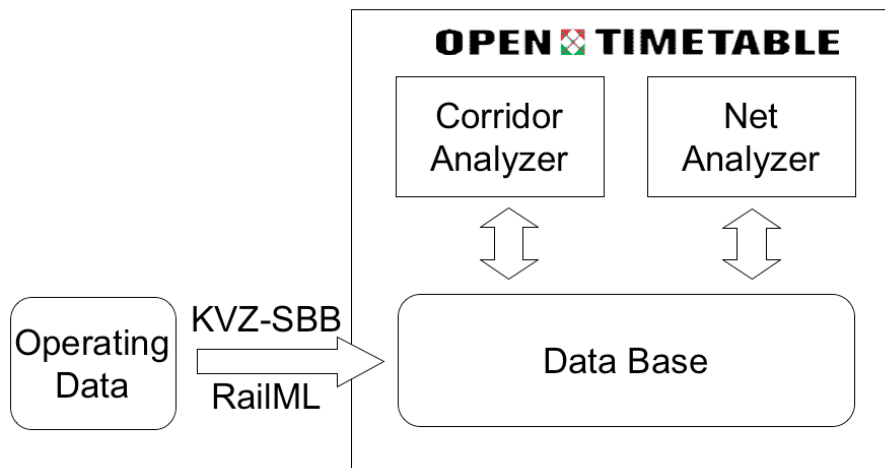


Figure 1: Data in different formats (e.g. RailML, KVZ SBB) is edited, analyzed and displayed by OpenTimeTable

OpenTimeTable uses two independent elements to analyze the data: the NetAnalyzer and the CorridorAnalyzer. The NetAnalyzer allows users to locate potential problems on the entire network. Users can define different types of limits such as the maximum number of delayed trains in a station or the maximum delay in a station for a train; OpenTimeTable then automatically generates reports when one of the limits is exceeded. Consequently, the critical points in the network and the delay prone trains in the timetable are easily detected.

Once these problems have been identified using the NetAnalyzer element, OpenTimeTable's CorridorAnalyzer element can be used to present schedule data from the selected corridor in a graphical timetable format. The graphical timetable produced in this analysis shows data for all the trains operated on the corridor over the user specified time period, including individual train paths, data for the median and mean running and/or a percentage cover area. Figure 2 shows an example graphical timetable for the corridor Rapperswil – Zurich – ZH Oerlikon. OpenTimeTable can also produce delay and capacity distribution diagrams for all analyzed points in the corridor.

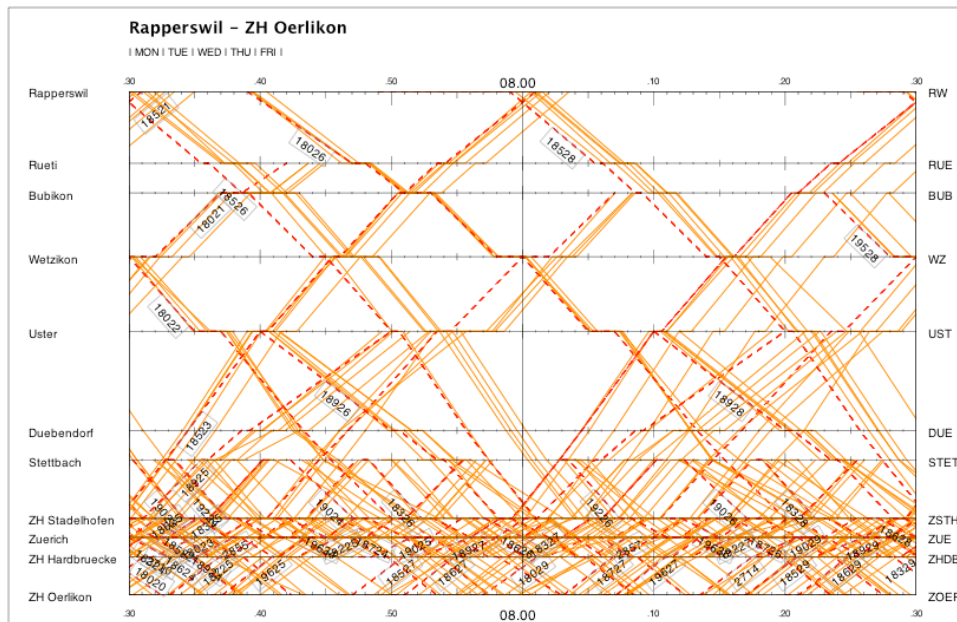


Figure 2: A graphical timetable produced using OpenTimeTable showing the planned (dashed lines) and all the running (solid lines) trains for 5 days in April 2004.

OpenTimeTable was developed in 2004 at the Swiss Federal Institute of Technology's Institute for Transportation Planning and Systems (ETH IVT) in cooperation with the Swiss Federal Railways (SBB).

2.2 Analysis of Delay in the Zurich Area

As part of a recent research project the ETH IVT used OpenTimeTable to evaluate delays and developed improvement recommendations for the Zurich area suburban rail network. The following conditions make Zurich's network particularly prone to delays:

- A large variety of different train categories – suburban trains, regional trains, fast trains, international trains and freight trains – operate in the Zurich area.
- All trains use the same track network in a repeating half hour schedule interval.
- Zurich's main station has a terminal plan, which requires a large number of crossing movements.
- There is limited capacity in many suburban stations and blocks around Zurich.

These conditions create many dependencies between trains. Therefore, even a small delay caused by a single train can destabilize the whole system. Under these conditions the strategy for achieving a stable network must be an accurate and feasible timetable, which provides selective slack inserts allowing trains to pass through the critical and capacity limiting points on schedule most of the time.

As part of the study OpenTimeTable was used with actual schedule data to identify different delay patterns and reasons for the delays. The main reason for delays in the

Zurich area is that the scheduled station dwell times are much too short and as a result the delay in all the stations increases (see Figure 3). Even the scheduled slack time for travel between stations is insufficient to eliminate the delays. A second problem is that many trains coming from outside into the Zurich network are late. As mentioned above, because of the high inter-dependencies between trains, the delays from outside the Zurich network increase delays on trains in the network.

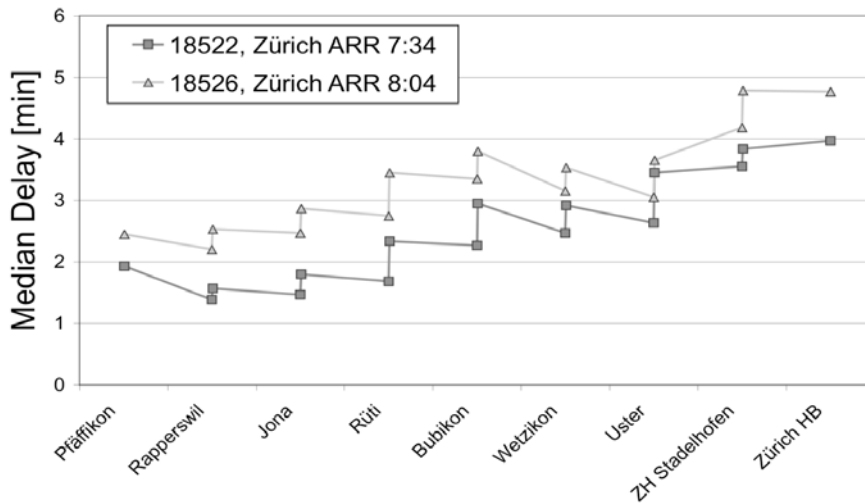


Figure 3: Median delay development of the S5 suburban train line (Pfäffikon-Zurich-Rafz) in January 2004 during the weekday morning rush hour.

After identifying the causes of delay using OpenTimeTable, we examined the reasons for train delay in detail. The analysis showed that scheduled dwell times are impossible to maintain. Over the last several years, the number of passengers using Zurich's suburban train network increased significantly (up to 175% increase of demand within the last 15 years on certain lines) but station dwell times were never adjusted to accommodate more passengers. In contrast to research completed in Den Haag [2] where on average 25% of the dwell time was unused, measurements made in Zurich show that the reason trains exceed the scheduled dwell time was due to the passenger boarding and alighting process. The research also concluded, based on the statistical analysis, that the dwell time could not be approximated a priori with one unique density curve.

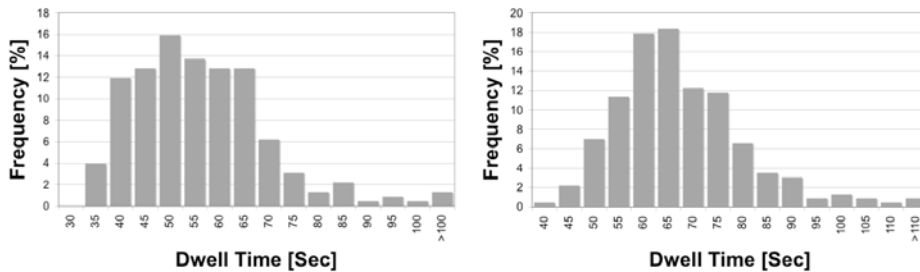


Figure 4: Dwell time distributions for Bubikon (left) and Uster (right) during the weekdays 2004 for the morning suburban rush hour train 18526

The same type of statistical analysis was completed of running times between two stations. The running time for a single train is affected by several factors, including occupied blocks, varying adhesion because of changing weather conditions, different passenger loads and the train operator behavior. Nevertheless a surprising result of this analysis was that the running time between two stations can be approximated in most cases by a Log-Logistic density function:

$$f(x) = \begin{cases} \frac{\alpha}{\beta} \frac{\left(\frac{x-\gamma}{\beta}\right)^{\alpha-1}}{\left[1 + \left(\frac{x-\gamma}{\beta}\right)^\alpha\right]^2} & \text{for } x > \gamma \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

Statistical analysis showed, that the shape of the curve does not change depending the time of the day, the stations connecting this section, the number of available tracks between the stations, the train category, the running time margins or the departing delay (see Figure 5 and Figure 6). Only the parameters α , β and γ depend on the mean travel time, the deviation and other factors. Additional research is needed to develop a better understanding of running time delay including specifying values for the parameters and estimating the train operator's influence.

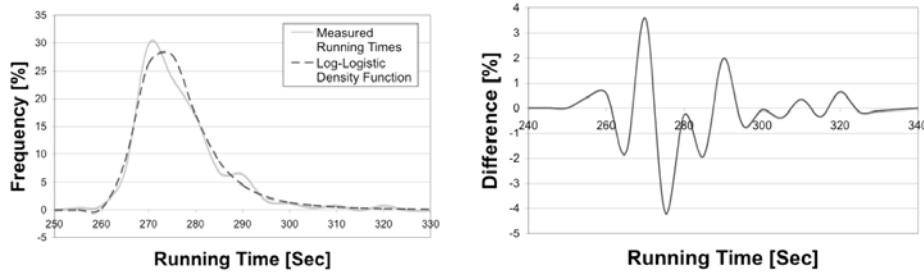


Figure 5: Comparison of the Log-Logistic density function to the measured distribution for the weekday morning rush hour S-Bahn Train 18526 in 2004 from Wetzikon to Uster (6.9 Kilometres whereof 4.0 Kilometres single track section).

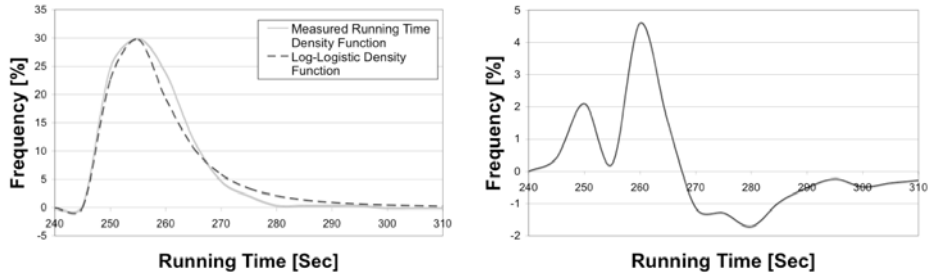


Figure 6: Comparison of the Log-Logistic density function with the measured distribution for the weekday morning rush hour S-Bahn Train 18526 in 2004 from Bubikon to Wetzikon (5.9 Kilometres single track).

The assignment of secondary delays on critical sub-networks or capacity bottlenecks can be identified with OpenTimeTable. However, a railroad simulation tool is needed to better understand the complete mechanism of delay development and interactions between trains on the network. Furthermore, such a tool allows users to test proposed changes and their consequences for new timetables. This type of analysis tool is described in the following section.

3 Simulation of Rail Networks

3.1 OpenTrack

OpenTrack [3,7] is a simulation tool for rail network planning based on a synchronous, event-driven simulation kernel. As a microscopic analysis tool it simulates the detailed behaviour of all railway elements (e.g. infrastructure, rolling stock, timetable) as well as the processes between them.

OpenTrack can provide users with a wide variety of outputs during and after a single simulation run. The program records physical data of every train such as position, speed, acceleration, energy consumption etc. as well as statistical data such as track usage, conflicts between trains and station delay data. Figure 7 is an example of a graphical timetable produced by OpenTrack showing the planned timetable compared to the simulated results of a disturbed timetable based on the median data measured in 2004.

Rapperswil - Zürich Oerlikon

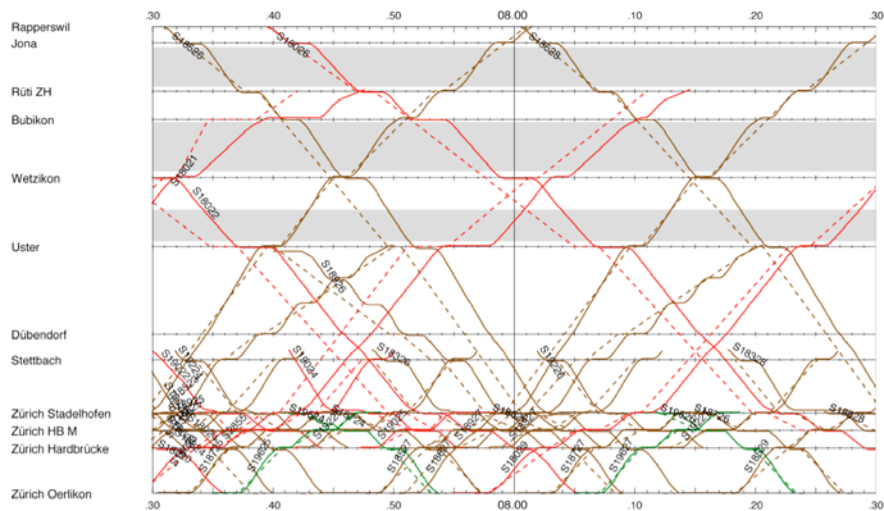


Figure 7: OpenTrack graphical timetable showing the planned (dashed lines) and a calculated (solid lines) timetable, the grey areas indicate single-track sections.

The simulation kernel of OpenTrack can be controlled either with a user-friendly graphical user interface (GUI) or through integrated Web Services, which allows OpenTrack to act as an embedded simulation kernel within another application.

3.2 Web Services

The Web Services concept uses a system of loosely coupled services that can be accessed via the Internet to complete a task. A Web Service itself is a modular application (or a part of an application) that offers open, internet-oriented, standards-based interfaces. In OpenTrack these services offer a programmatic interface based on the exchange of SOAP (Simple Object Access Protocol) messages, which contain the railway relevant data (e.g. timetable, railway infrastructure or rolling stock data) in the RailML [4,8] format, an open data exchange format based on the Extended Markup Language (XML).

Figure 8 shows an example of an exchange of timetable data where OpenTrack was the server, which responds (`getRailML_Timetable_Response`) with the RailML-based timetable data after receiving a request (`getRailML_Timetable_Request`). In a different role OpenTrack could also act as a client of a transaction. For example OpenTrack could ask a server offering rolling stock oriented Web Services for the technical specifications of a locomotive which had not previously been used in it.

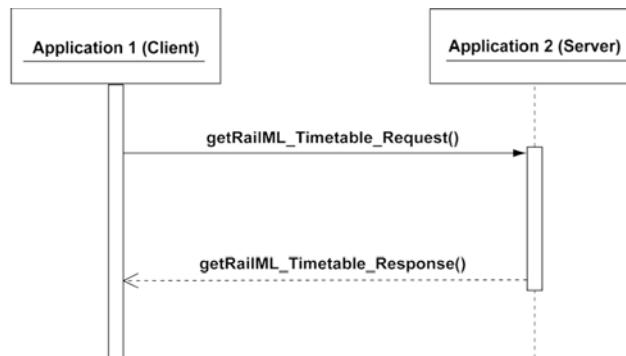


Figure 8: UML sequence diagram showing the transfer of timetable data from a server to a client.

Railway oriented Web Services in combination with standardized XML-based file formats for railway data (e.g. RailML) can significantly increase the functionality of many railway tools by easily delegating some functionality to specialized modules.

4 The Timetable Planning Process as a Closed Control Loop

Railway scheduling is a challenging process. Today the experience of human schedule planners is a fundamental requirement for creating a robust and efficient timetable. Because of their great complexity, most new timetables are simply minor adjustments of existing timetables. Creating a new timetable from scratch, like the new Bahn 2000 timetable in Switzerland, is extremely time consuming. Therefore, only a few variants, or even just one option, can be developed.

4.1 OpenTimeTable and OpenTrack in the timetable planning process

The combined use of OpenTimeTable and OpenTrack can help accelerate the schedule planning process and can be used to evaluate several timetable options from the perspective of different variables (for example different estimated passenger demands). A significant advantage of using both tools together is the simple and fast recognition of delay prone trains and network conflict points for an actual (in operation) or planned timetable. Once the problems with this schedule are identified railway schedules can be changed iteratively to address the specific problems. In a more thorough evaluation, different delay scenarios can also be tested using simulation. In this way, the robustness of the schedule revision can be estimated and compared to existing conditions or alternatives.

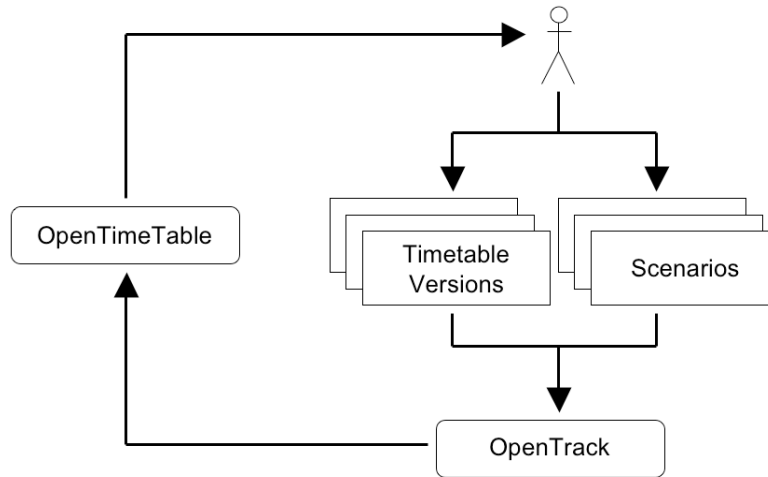


Figure 9: Timetable development using OpenTrack and OpenTimeTable.

A good example of this process is a project recently completed by the ETH IVT for reducing delays in the Zurich area with special focus on Stadelhofen Station. Stadelhofen station serves 19 or 20 trains per hour and direction during the rush hour (see Figure 10). The analysis showed that simple actions like changing the train order, making changes to which platforms they call at, or making small adjustments in the schedule, have a large impact. These changes and their effects on the whole network were evaluated quickly and comprehensively using OpenTrack and OpenTimeTable together. Changes similar to those tested in this research project were actually implemented and confirmed the study prediction: the delay decreased and additionally, one more train could be scheduled to stop at Stadelhofen during the rush hour.

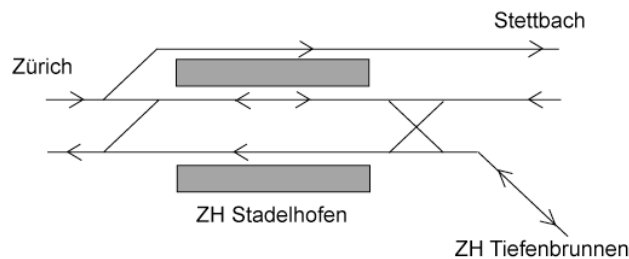


Figure 10: Track layout for the station ZH Stadelhofen.

4.2 Delay scenarios

OpenTrack also allows users to test various different delay scenarios. One type of primary delay already implemented in OpenTrack is a large variety of rolling stock malfunctions and infrastructure failures. Further delay scenarios could include the variation of the dwell time at a station and the variation in train operator behavior.

Calculating the station dwell time is a good example of the type of application that could be realized with Web Services introduced in Section 3.2 above. The basis for such an application could be the density function information gained using OpenTimeTable, formulas for the boarding and alighting process combined with knowledge about the quantity of involved passengers [6] or another simulation tool (for example a pedestrian movement simulation tool [1]). Similarly, the train operator’s influence on running times between stations can be modeled using the train performance, acceleration and breaking parameters.

4.3 The automated timetable development process

The timetable planning process presented in this paper still requires a certain amount of time to complete depending on the size and complexity of the network. Nevertheless, many different possible timetables can be evaluated using this process by focussing on the network’s capacity problem points.

To close the loop, in other words, automate the entire process of schedule development, an optimization application as proposed in Figure 11 is needed. The main problem in realizing this objective will be the formulation of a reasonable optimization function. Once the optimization function is developed, evolutionary algorithms could be used to compute next timetables.

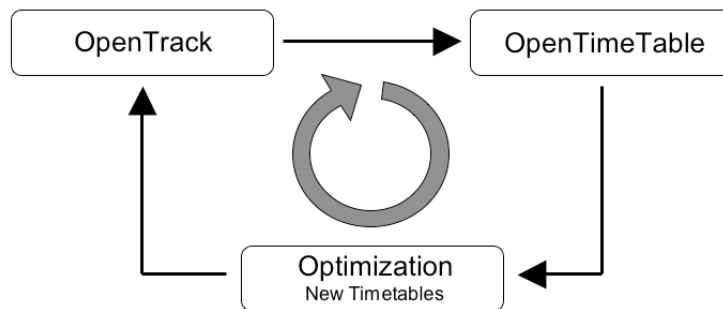


Figure 11: Control loop of the planning process

A good approach to the problem of creating an automated railroad timetable development process is not to execute the whole process in one single program, but rather to combine existing applications with a common data format (RailML) in a Web Services environment. This approach combines the advantages of existing programs and reduces the development effort. The loop (create timetable – evaluate timetable – revise timetable) could be repeated until a termination criterion stops the process. Thereby, many different timetables could be evaluated and compared in the process of developing an improved timetable.

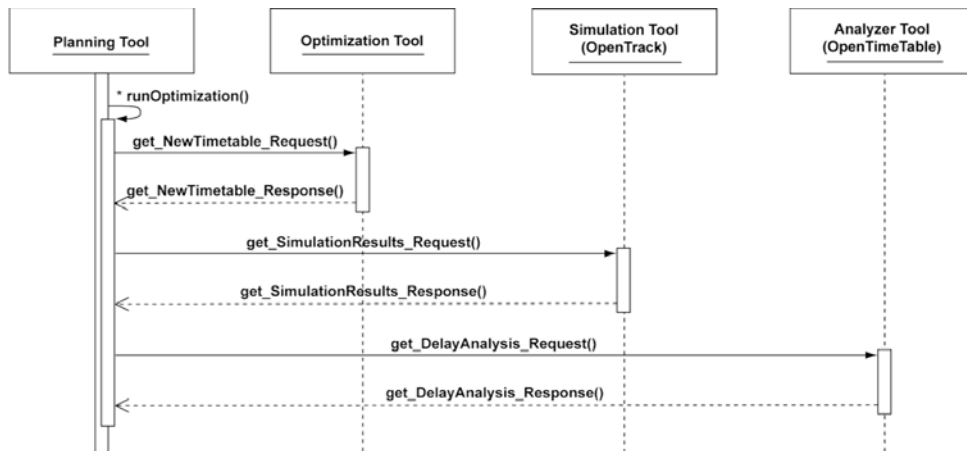


Figure 12: UML sequence diagram showing the data transfers made during the scheduling process.

5 Conclusions

In our opinion, the railroad timetable planning process can be optimized and accelerated through the combined use of simulation and analysis tools. Furthermore, the use of Web Services creates an easy and powerful process whereby independent modular programs can interact and exchange data with each other, making it easier to combine programs and thereby develop improved timetables. OpenTimeTable and OpenTrack, two computer programs developed at the Swiss Federal Institute of Technology, and the RailML data structure provide initial building blocks for this approach. They allow different scenarios, self defined or based on real schedule data, to be used in the evaluation of timetable robustness.

Finally, once an optimization application element is developed through combined use of all three tools, possibly in a Web Services type environment, it will be possible to create and evaluate many different railroad timetables and demand scenarios, a process which is impossible today given the complexity of developing and evaluating railroad schedules.

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