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OPENTRACK – A TOOL FOR SIMULATION OF RAILWAY NETWORKS

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Abstract: *OpenTrack began a few years ago as a research project at the Swiss Federal Institute of Technology. The aim of the project, Object-oriented Modelling in Railways, was to develop a user-friendly tool that would answer questions about railway operations by simulation. One of the tasks OpenTrack supports is calculation of minimum headways (headway calculation), e.g. using the OpenTrack tool Headway Calculator. Based on a number of input parameters, the headway calculator computes the minimum headway between two trains and is able to identify the critical block section. The two trains may vary in type (e.g. intercity, commuter, freight, etc.), route and stopping pattern. The headway calculation works for fixed block (discrete block), moving block and CBTC systems. During the simulation predefined trains run on a railway network according to the timetable and under the constraints of the signalling system. After a simulation run, OpenTrack can analyse and display the resulting data in the form of diagrams, train graphs, occupation diagrams and statistics.*

INTRODUCTION

Railroad planning is particularly challenging because different improvements can be used to achieve project objectives; improvements can be divided into three general categories: infrastructure, rolling stock, and operations. Improvements in each category need to be evaluated against improvements in other categories to develop the optimal investment plan.

A good example of a structured approach to trading off different types of improvements in these categories is the Swiss National Railroad's (SBB) Integrated Product Planning Process [1]. The SBB views this process as a Planning Triangle with three elements at the corners: Products, Rolling Stock, and Infrastructure. Products are the services and schedules operated (e.g. commuter rail, intercity rail, freight); rolling stock means the type of rolling stock used to provide a particular service; and infrastructure consists of the physical system (e.g. tracks, signal systems, stations). SBB planners use iterative techniques to evaluate changes in each of these elements to optimize the system as a whole. This triangular depiction effectively communicates the relationship between the three elements and their ability to meet market demand.

In an example of this process, the SBB decided to use tilting trains to provide high speed service (a rolling stock solution) rather than fully rebuilding tracks on a particular corridor (an infrastructure solution) because the former was found to be more cost effective.

Computer simulation is a particularly important and useful tool for evaluating different railroad improvement strategies for the following reasons:

• Understanding Capacity – Railway capacity is not intuitively obvious. Even lines with very little service may be operating at capacity.

• Highly Interrelated Infrastructure – An infrastructure improvement in one location can have significant impacts in another location, sometimes far from the improvement. A rail simulation program can identify the impacts of such changes throughout the modelled network.

• High Cost of Rail Infrastructure – Improving a railroad is expensive, not only are the physical improvements costly, but costs for taking a line out of service during construction and for additional right-of-way can be significant. Furthermore, a poorly planned improvement will increase the railroad's long term operating costs and problems.

Given these factors, many rail-planning experts recommend completing as much modelling as possible before starting a railroad improvement program. In general, the more modelling done up front, the less expensive the overall project will be, since modelling enables the plan to be refined to its most essential elements [2].

The first step in using computer models in the railroad planning is to calibrate the base case model. This should accurately replicate observed railroad operations with the existing infrastructure, rolling stock, and schedules. Once the model has been calibrated it can be used to investigate many issues including estimating the stability of new timetables, determining the minimum infrastructure requirements for a given timetable, or evaluating the impact of rolling stock changes. A significant benefit of models is their ability to evaluate the impact of incidents or time-based network changes (e.g. maintenance) on railroad operations.

Computer simulation is especially valuable for railroad planning since, once developed and calibrated, models can be used for the comparison of the benefits, impacts, and costs of various different improvement packages. To analyse more than a few improvement packages by hand would be prohibitively time consuming. Thus, effective railroad simulation models enable planners to identify and evaluate more alternatives, ultimately leading to more creative and comprehensive problem solutions.

While computer simulation is an excellent tool for analysis and planning of railroads, railroad network simulation programs have the following limitations:

- Programs must be validated to actual conditions.
- Yard operations must be modelled separately.
- Resource constraints such as crew scheduling are largely ignored (although some specialized software does address resource constraints).
- Simulations only include the modelled study area.
- Simplifying assumptions generally create an inherent optimism about overall congestion, schedule adherence, and recoverability [3].

Given these limitations, especially the last one, it is critical that all simulation results be carefully reviewed and discussed with those familiar with operations. There is no substitute for real experience in the planning process.

OPENTRACK RAILWAY SIMULATION SOFTWARE

OpenTrack was developed at the Swiss Federal Institute of Technology's Institute for Transportation Planning and Systems (ETH IVT). The project's goal was development of a user-friendly railroad simulation program that could run on different computer platforms and could answer many different questions about railway operations [4]. Figure 1 illustrates the three main elements of OpenTrack: data input, simulation, and output.

OpenTrack is a microscopic synchronous railroad simulation model. As such it simulates the behaviour of all railway elements (infrastructure network, rolling stock, and timetable), as well as all the processes between them. It can be easily used for many different types of projects, including testing the stability of a new timetable, evaluating the benefits of different long-term infrastructure improvement programs, and analysing the impacts of different rolling stock.

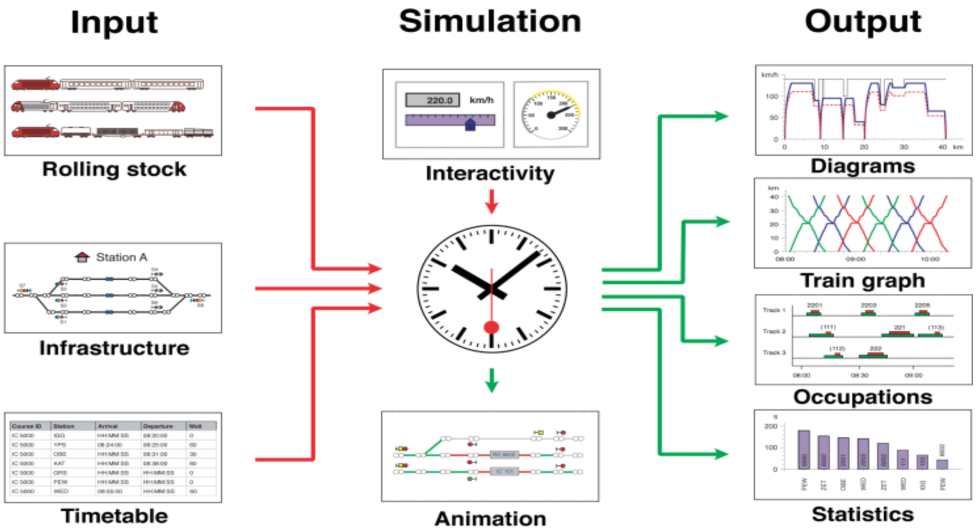


Fig.1 Data flow in simulation of railway operation

Input Data

OpenTrack manages input data in three modules: rolling stock (trains), infrastructure, and timetable. Users enter input information into these modules and OpenTrack stores it in a database structure. Once data has been entered into the program, it can be used in many different simulation projects. For example, once a certain locomotive type has been entered into the database, that locomotive can be used in any simulation performed with OpenTrack. Similarly, different segments of the infrastructure network can be entered separately into the database and then used individually to model operations on the particular segment or together to model larger networks.

Train data (locomotive and wagons) is entered into the OpenTrack database with easy to use forms displayed using pull down menus. Infrastructure data (e.g. track layout, signal type/location) is entered with a user-friendly graphical interface; quantitative infrastructure data (e.g. elevation) is added using input forms linked to the graphical elements. Following completion of the RailML [5] data structure for rolling stock and infrastructure, OpenTrack will be modified to enable train and infrastructure data to be directly imported from RailML data files.

Timetable data is entered into the OpenTrack database using forms. These forms include shortcuts that enable data input to be completed efficiently. For example, users can designate hourly trains that follow the same station stopping pattern an hour later. Since OpenTrack uses the RailML [5] structure for timetable data, timetable data can also be entered directly from various different program output files as well as database files.

One advantage of OpenTrack is that it enables users to adjust many variables that impact railroad operations. For example, users can simulate the impact of weather on traction by specifying the adhesion scenario (good, normal, bad). OpenTrack then estimates locomotive traction power using a percentage (also user-defined) of that calculated using the Curtius and

Kniffler formula. [6] While OpenTrack provides standard default values for all variables, having the ability to adjust variables makes the program quite useful.

Simulation

In order to run a simulation using OpenTrack the user specifies the trains, infrastructure and timetable to be modeled along with a series of simulation parameters (e.g. animation formats) on a preferences window. During the simulation, OpenTrack attempts to meet the user-defined timetable on the specified infrastructure network based on the train characteristics. OpenTrack uses a mixed continuous/discrete simulation process that allows a time driven running of all the continuous and discrete processes (of both the vehicles and the safety systems) under the conditions of the integrated dispatching rules.

The continuous simulation is dynamic calculation of train movements based on Newton’s motion formulas. For each time step, the maximum force between the locomotive’s wheels and the tracks is calculated and then used to calculate acceleration. Next, the acceleration function is integrated to provide the train’s speed function and is integrated a second time to provide the train’s position function [6].

The discrete simulation process models operation of the safety systems; in other words, train movements are governed by the track network’s signals. Therefore, parameters including occupied track sections, signal switching times, and restrictive signal states all influence the train performance. OpenTrack supports traditional multi-aspect signalling systems as well as new moving block train control systems (e.g. European Train Control System – ETCS signalling).

OpenTrack is a dynamic rail simulation program. As such, the simulated operation of trains depends on the state of the system at each step in the process as well as the original user-defined objective data (e.g. desired schedule).

A simple way of describing dynamic rail simulation is that the program decides what routes trains use while the program is running. For example, when building the network, users identify various different routes that trains can use between two points; OpenTrack decides, during the simulation, which route the train will use by assigning the train the highest priority route available. If the first priority is not available, OpenTrack will assign the train the second highest priority route and so on.

OpenTrack’s dynamic nature allows users to assign certain attributes to specified times in the simulation. Thus, users can assign a delay to a particular train at a given station and time, rather than being limited to assigning a delay at the start and using it through the entire simulation. Similarly, users can define other types of incidents (e.g. infrastructure failures, rolling stock breakdowns) for particular times and places.

Finally, dynamic simulation enables users to run OpenTrack in a step-by-step process and monitor results at each step. Users can also specify exactly what results are displayed on the screen. Running OpenTrack in a step-by-step mode with real time data presented on screen helps users to identify problems and develop alternative solutions.

Output

One of the major benefits of using an object-oriented language is the great variety of data types, presentation formats, and specifications that are available to the user. During the OpenTrack simulation each train feeds a virtual tachograph (output database), which stores data such as acceleration, speed, and distance covered. Storing the data in this way allows users to perform various different evaluations after the simulation has been completed.

OpenTrack allows users to present output data in many different formats including various forms of graphs (e.g. time-space diagrams), tables, and images. Similarly, users can choose to model the entire network or selected parts, depending on their needs. Output can be used either to document a particular simulation scenario or as an interim product designed to help users identify input modifications for another model run [7]. Figure 2 shows an example of results from a simulation. This diagram shows a speed-distance diagram including signal system on the infrastructure. The red line represents the static speed profile and the blue line shows speed behaviour of the running train.

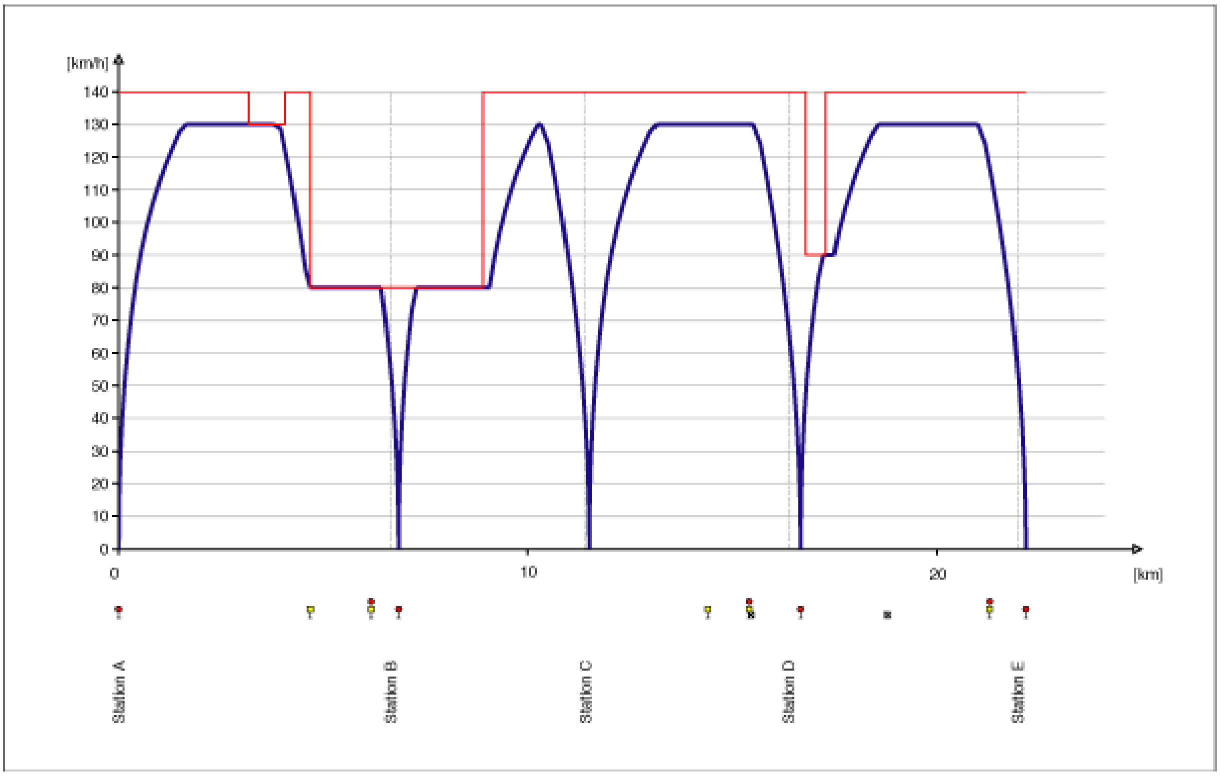


Fig 2: Output example - Speed-distance-diagram

Train graph (Fig. 3) of the Lötschberg line shows possible conflicts if this timetable would to be introduced. Circles on the graph describe different types of conflicts that are identified during simulation. Examples could be delay at the arrival or train stopping for the red signal.

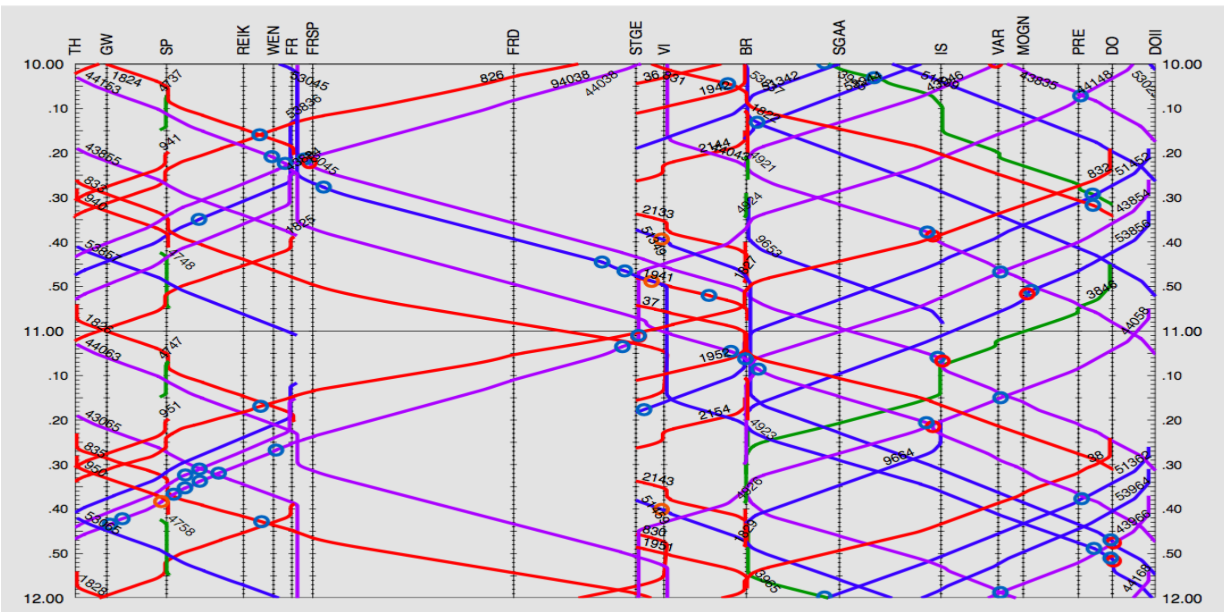


Fig 3: Output example - Train graph at Lötschberg line

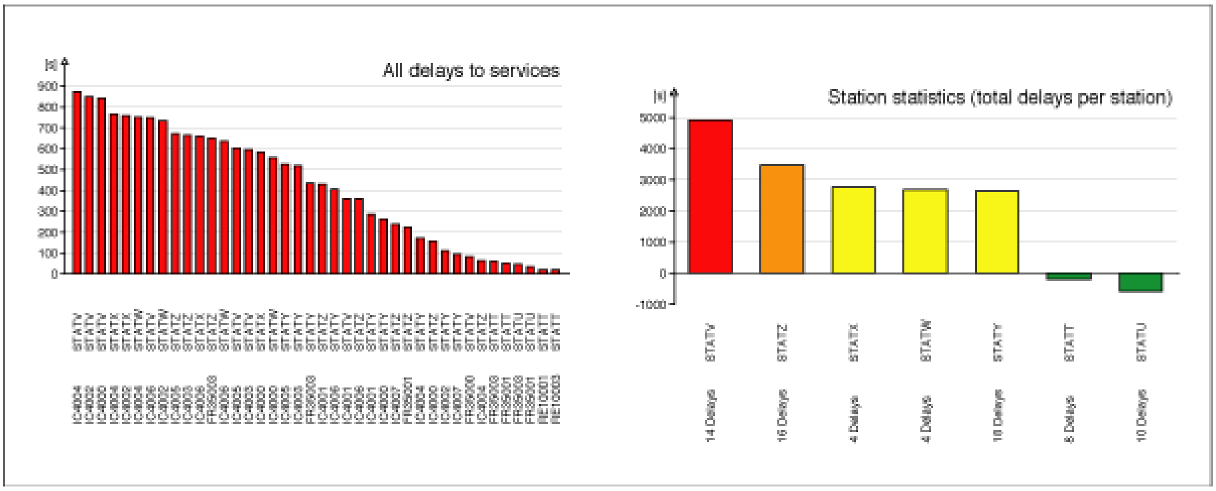


Fig 4: Output example – Delay statistics

Another example of the output results is shown in the next figure. It shows delay statistics from two perspectives. First, delays of each train in seconds are shown and on the other hand, total delays for each station are presented. In this way, one is presented with an overview of both the most ‘problematic’ trains and stations.

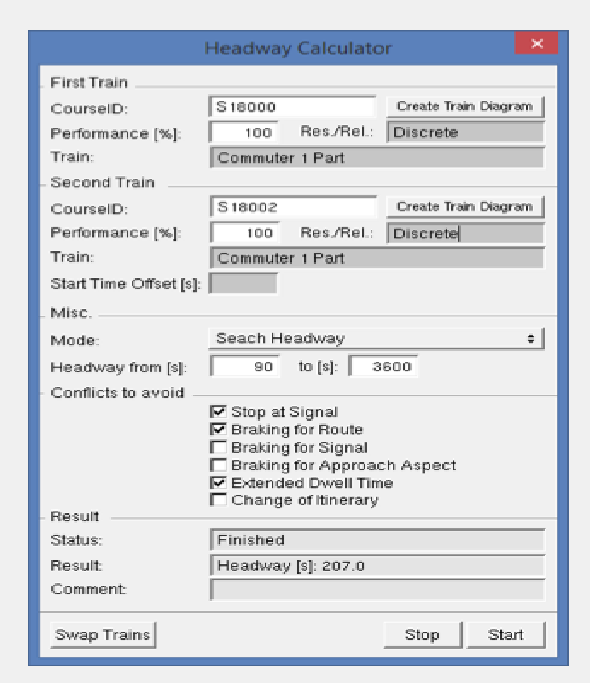
OPENTRACK AND API

The Open Track API (application programming interface) is able to communicate with a 3rd party application (over the internet). OpenTrack accepts Commands (messages to OpenTrack) and sends Status Messages (Messages from OpenTrack). Most importantly, these messages are designed such that they correspond to those exchanged in a real-world railway system between trains, interlocking and dispatching units. OpenTrack Dispatcher acts as the replacement of the reality, since the same type of information is exchanged as in reality; namely, commands (messages) go to OpenTrack, whereas Status Messages come from OpenTrack [7].

OpenTrack API’s application offers an unlimited number of possibilities, starting from implementation of customer-specific dispatching algorithms to in-depth evaluation of railway operations, connections between trains and circulation of train sets. The possibility of development and analysis of new concepts in train control, such as optimization of energy consumption, reduction of delays and avoidance of bottlenecks and conflicts is of great importance.

AUTOMATED HEADWAY CALCULATION FOR RAILWAYS

Today, one of the main goals of the railway system is to maximize the occupancy rate of the lines and stations. This ensures the maximum utilization of the railway system capacity. One of the ways to achieve this goal is to calculate minimal possible headways on the network using OpenTrack’s function called Headway Calculator (Fig. 5). Since it is known that there is no perfect block size, but this depends on many different parameters, simulation represents a perfect tool for calculating both block size (when using block-control approach) as well as minimum headways. The headway calculation of OpenTrack works for fixed block (discrete block), moving block and CBTC systems. Introduction of Automatic block signalling (ABS) system has increased railway overall capacity; furthermore, calculating minimum possible headways will enable maximal exploitation of existing capacity.



The importance of any modelling system lies in the accurate representation of reality. For this reason, OpenTrack takes all important parameters into consideration when calculating headways; for example, every possible combination of trains (train type, itineraries, stopping patterns, etc.). Furthermore, by using simulation for calculation of minimal headway, one can also ensure the exact picture of signalling system. This means that the accurate number of signals needed and, consequently, the exact estimation of costs need for a specific simulated scenario can be provided. Based on a number of input parameters, the headway calculator computes the minimum headway between two trains and is able to identify the critical block sections.

Fig 5: Headway Calculator

APPLICATION OF OPENTRACK FOR CALCULATING HEADWAY AT NEUSIEDLERSEEBAHN (NSB)

The NeusiedlerSeeBahn is responsible for the line from Neusiedl am See to Pamhagen (36.1km) in Austria. The branch line from/to Eisenstadt is located at Neusiedl am See and Pamhagen is the last station in Austria before the Hungarian border. From Neusiedl am See a line leads to Parndorf Ort where there is the connection to the Eastern line of Austrian Railways
which is connecting Vienna and Budapest. People living at the villages located between Neusiedl am See and Pamhagen typically go for work to Vienna every single day of the week. Therefore, the NSB is interested in offering shorter traveling times to Vienna. To achieve this goal some investments were done in the last years to increase the track speed. OpenTrack has been successfully used to evaluate the shortenings of running times for local trains and regional trains, as well as for calculating minimum headway.

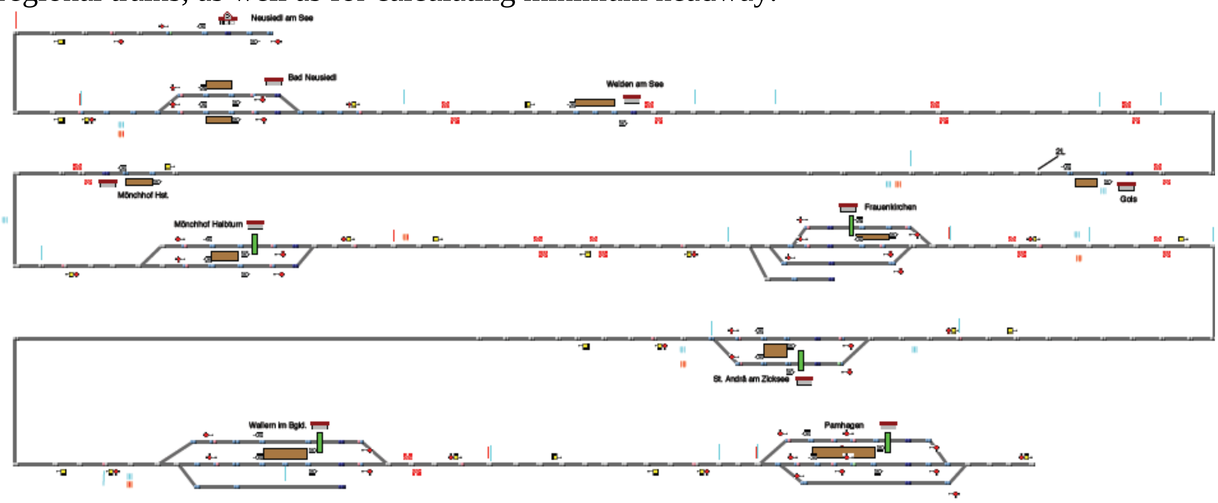


Fig 6: Infrastructure layout of the line form Neusiedl am See to Pamhagen

The layout presented in the Figure 6 includes all information needed for the calculation of headway; these are track speeds, radius, gradient and other features. Using all infrastructure and rolling stock parameters, headway calculator has come to a number of 678 seconds from Pamhagen to Neusiedl am See (Figure 7). This means that the minimum time between two trains on the track going in the same direction should not be shorter than ca. 11.3 minutes.

One can clearly see the critical block section between Mönchhof and Bad Neusieldl am See. By calculating minimum headways, one will make sure to avoid conflicts such as 'the red signal', which may occur when the headway is too short and the train running behind the first train has to stop and wait to enter the block.

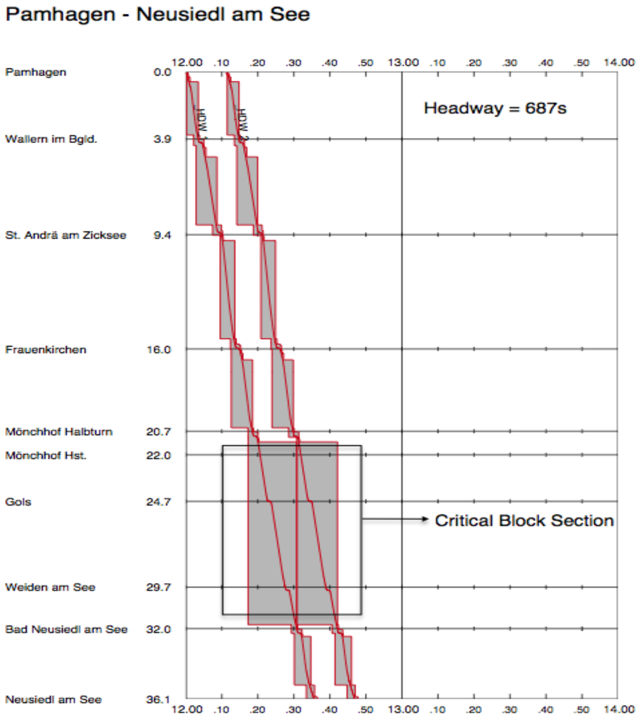


Fig 7: Calculated Headway = 678s

CONCLUSION

OpenTrack is an efficient and effective railroad simulation program. It has been used successfully in many different railway planning projects throughout the world. The program's use of object-oriented programming and the RailML data structure makes it particularly effective since the program can be modified relatively easily to address specific applications and since data can be transferred easily to and from other programs based on RailML. Therefore, it is highly recommended to use it for simulation of railway operations because it covers a wide range of possible output data that can be used in decision making processes.

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OPENTRACK – ИНСТРУМЕНТ ЗА СИМУЛИРАНЕ НА ЖЕЛЕЗОПЪТНИ МРЕЖИ

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Ключови думи: *симулиране на железопътни превози, извършени превози, разписание, изчисляване на капацитета.*

Резюме: *Open Track е създаден от Швейцарския федерален технологичен институт преди няколко години като проект. Целта на проекта е да се създаде подходящ инструмент за провеждане на симулации при железопътните превози. Една от основните задачи на Open Track е да се изчисли минималния пробег на подвижния състав в железопътния транспорт, като се използва инстумента Open Track Headway Calculator. Въз основа на няколко входни параметъра, инстументът изчислява какво трябва да бъде минималното разстояние между два влака, като позволява да се определи критичната дължина на превозните средства при тяхното движение на блок-влакове. Съответно двата влака могат да бъдат различни в замвисимост от вида (напр. междуградски, пътнически или товарни влакове), както и маршрута и спирачната система. Изчисляването на разстоянието е възможно когато блок-влаковете са в статично и динамично положение, както и при CBTC системите. Самата симулация е извършена в случая, когато влаковете се движат по железопътната мрежа при точно определено разписание и при наличието на система за сигнализация. При провеждане на симулацията, инструментът Open Track позволява получените данни да се анализират и запишат под формата на диаграми, схеми с влакове, графики и таблици..*