Automated planning of timetables in large railway networks using a microscopic data basis and railway simulation techniques

A. Radtke¹ & D. Hauptmann²

¹Institut für Verkehrswesen, Eisenbahnbau und –betrieb, University of Hanover, Germany
²Rail Management Consultants GmbH, Germany

Abstract

To enhance the flexibility in the planning process and to support the operational demands of a railway, the software system RailSys has been enhanced with a search engine to provide possible train slots in an existing timetable. The slot search engine operates on the detailed RailSys database to provide feasible solutions. The search engine takes into account a correct running time calculation on the basis of actual train characteristics (length and weight), infrastructure parameters (e.g. gradient, speed profiles), the headways of other trains and operational demands (length of the platforms, correspondence, stopping patterns).

The second part of the paper deals with the Client-Server architecture of RailSys and the actual use of this technology. Therefore, the paper will describe the interaction between the NEMO (Network Evaluation MOdel) Model and RailSys and illustrate the workflow between models using microscopic and macroscopic data. The paper will conclude with an explanation of how the system will be state of the art, using a microscopic and detailed model of the infrastructure in order to generate proven and feasible results in the planning process. Furthermore, the paper will provide an overview of more useful fields for the application.

The paper will illustrate examples on large parts of the German railways network and provides an outlook of the further development in order to generate timetables automatically. So far Railsys and NEMO have been used in a multitude of applications concerning timetable construction and simulation, railway operation and infrastructure planning at RMCon and IVE in various countries around the world.

Keywords: planning of railway operation, automatic timetable construction, train path search algorithm, railway simulation, client-server solution.
1 Introduction

Timetables of single lines, small and extensive railway networks, such as the German railway network, are often predefined by several unchangeable boundary conditions. The layout of track infrastructure (e.g. single track sections, availability of sidings, signalling system) and the rolling stock in use (e.g. maximum speed, traction effort) form the fundament of these boundary conditions. Besides these fundamental conditions, which have an effect on every individual train run, there are additional conditions that arise from the interaction of different trains and from the passengers’ demand. Basic interval timetables for suburban and intercity passenger services are very attractive and allow a passenger to change trains comfortably.

But the objective to run consistent passenger services decreases the flexibility of the operational program, especially for freight trains. Besides regular and high priority freight trains who have fixed slots that constrain the timetable further more, the bulk of freight trains, though planned in a timetable, are not running according to their timetable. Customer demand of flexible departure times for freight trains or changes of the freight train characteristics (weight of the train) require a flexible way to assign feasible slots to those trains.

Existing timetables often do not offer many possibilities for additional train runs due to the boundary conditions. Manual methods reach their limits easily, especially in extensive networks. Conventional timetable construction programs can only support the manual detection of possible slots.

Therefore, the timetable construction and operational simulation program RailSys has been enhanced with a search engine for the detection of available train slots. This enhancement was part of a research project supported by the BMBF (German Federal Ministry of Education and Research) with project responsibility by the TÜV academy Rheinland, Berlin, Brandenburg (safety standards authority energy- and environment).

Furthermore, a problem of the strategic planning has to be discussed. In order to investigate the impact of new infrastructure and operating programs in the future, models like NEMO can provide results on a macroscopic level. Therefore, NEMO generates train runs on the railway network (network load) according to the passenger and freight demand prognostics taking into account operating rules of the railway. Using systems like RailSys in the following step to obtain a closer detailed view on infrastructure or timetable aspects, a reasonable amount of modelling time is required for this task. Using the slot search engine described above, a network load of one NEMO scenario can be transferred into a RailSys timetable. The degree of automation of this timetable generation cannot be answered at the time preparing this paper. However, we expect to decrease the effort to construct one feasible timetable about 80 percent on the basis of a NEMO network load. This means, instead of constructing and simulating only one timetable for a time horizon of 10+ years approximately five timetables can be constructed and simulated in the same time [6].
2 RailSys: simulation and timetable construction

The timetable and infrastructure management program RailSys [1,2,3] is a software system for analysis, planning and optimisation of operational procedures and facilities in rail transport networks of any size. Operational procedures are realistically displayed on desktop computers and the investigation of large network systems is just as easily accomplished as the processing of specific local problems. Simulations on a microscopic detailed database are a long proven and very efficient way of optimising proposed infrastructure and operations for rail transport systems. Simulations can reduce and save planning and operational costs. It is obvious, that practical trials and experiments are no realistic alternative to simulations.

RailSys is based on the synchronous simulation. This type of simulation is based on the fact that all trains are in the model running according to their timetable. Therefore, it is possible that different trains influence other trains due to delays or dispatching actions. In contradiction, the asynchronous simulation handles all trains according to a hierarchy assigning trains step by step into the model starting with high priority trains and ending with low priority trains. It is evident, that only the synchronous simulation models can provide indicators like On-Time-Running (OTR) performance or the development of delay situations in railway networks. OTR values are very important for the design and operation of business rules and penalty regimes between infrastructure and train operating companies.

The synchronous simulation can be differentiated into two parts. The first type is the simulation of a timetable to investigate the effects of conflicts spreading throughout a network. During the timetable simulation there will be no introduction of additional delays, e.g. dwell time extensions, into the model. The second part can be named as operational simulation (formerly stochastic or multiple simulation). This operational simulation includes the introduction of additional delays according statistical rules. To obtain a sufficient statistical basis for the evaluation in general between 50 and 200 different timetables including different delays have to be simulated. Both the timetable and operational simulation use powerful dispatching algorithms to model the occurrence of delays in the real time dispatching.

The static timetable construction depends on the detailed microscopic depiction of the infrastructure and the signalling systems. The microscopic infrastructure is described by a node-edge model containing the relevant information. In this case, microscopic describes the fact that all information regarding the infrastructure can be used in the model without limitations.

Both elements (infrastructure and signalling system) are used to calculate correct running and track occupation times and additionally, to detect conflicts between trains throughout a network. The aim of the static timetable construction is to deliver a conflict free timetable. However, without simulation of that timetable it is not possible to provide quality of service figures like OTR values.

The timetable construction starts years before placing the timetable into operation, and includes various timetable conferences and meetings to co-
ordinate all (often contradicting) demands of infrastructure companies, train operating companies and the public. This process finishes after the publication of the timetable. The timetable construction is embedded in the long term planning phase on the one side. On the other hand, the short term planning continues the timetable construction due to ongoing changes in various parameters (special events, available traction, planning of possessions etc.) and is completed in the real time day to day ad-hoc dispatching.

A very impressive example of the possibilities of detailed timetable construction and synchronous simulation are the projects performed in Nordrhein Westfalen [3].

It is evident, that all processes:

- Long Term Planning (LTP)
- Timetable Construction
- Short Term Planning (STP)
- Ad-Hoc-Dispatching

can and should be supported by a synchronous simulation as an important ad on for the static timetable construction or ad-hoc dispatching. However, though the simulation technique is proven and available, it is still not state of the art in the planning process to use this technique.

Furthermore, the slot search engine can be used in all those planning stages and opens even more fields of applications for the near future.

3 The slot search engine

Computer aided construction of train slots in existing timetables of large railway networks is a complicated and time consuming process. Integrated into RailSys, the new slot search engine benefits from all the advantages that are provided by the complete software framework. To ensure exact results that can be used immediately by the timetable planner, the search uses a highly detailed microscopic model of the railway network. According to the given mandatory and optional input data and the operational program, the search engine finds a conflict-free, optimal and suitable train path. The automatically generated train runs can be altered interactively using the timetable tool. The reliability and stability of the resulting timetable can be evaluated immediately with the help of the timetable and operational simulation [7].

There are two options for the train slot search. The first option is to construct a new train from scratch and integrate it into the timetable. The second option is to re-route and rearrange an existing, conflicting train such that it fits flawlessly into the timetable. Both situations can be handled by RailSys.

Additionally, a complete conflict-free timetable can be build up by importing a timetable using the train slot search engine. In this application the trains are ordered by their priorities (the high-priority trains come first). A free train slot is searched for every train, following their rules of priority. The result is a conflict-free timetable. The import data can even be generated by macroscopic models.
which commonly deliver less detailed information about the train runs. Using the train slot search engine all missing microscopic data is determined automatically.

3.1 Parameters

To use the search engine the user has to specify the following parameters:

- Start time of the train: the train slot will start at or after this time.
- Train type: the physical description of the train (dynamical parameters, weight, length, maximum velocity, operational parameters, signalling system etc.).
- Start and target station. Additionally, the user can specify via-stations to for the train routing.
- Optionally, the user can specify stopping times and exact via-tracks at every station.

Figure 1 shows the current dialog (RailSys Version 3.0.40, January 2004) to control the parameters of the search engine. The weighting function takes into account any combinations of the parameters 'running time', 'stopping time', 'difference to proposed start time'. Further development will also use the parameters 'train path pricing', 'energy consumption' or 'time allowance'.

In this implementation, the slot search does not take into account a ranking of trains. Therefore, one parameter allows the low prioritised trains to be ignored. In the future, there will be more research to enhance the algorithm, taking into account the ranking of trains and movement of already “fixed” trains. However, it is obvious, that this approach will increase the computing time significantly because the amount of possible feasible solutions will increase as well.

Other important parameters which can be controlled by the user are as follows:

- “Bending allowed”: If this parameter is switched on, the search engine also takes into account slots that need longer running times than the scheduled running time (minimum running time and the running time margin for the train type). Thus the train can slow down to use a slot between slower trains.
- “Maximum difference to start time”: The user can limit the maximum allowed difference to the start time to reach a special starting slot (this parameter is used in combination with the cost factors).
- “Maximum stopping time”: The stopping time can also be limited to avoid excessive stopping times (this parameter is used in combination with the cost factors).
- “Maximum running time allowance”: If “Bending allowed” is selected this parameter controls how much the algorithm is allowed to extend the running time.
- “Minimum buffer time to preceding/following train”: This is the margin between the occupation times of the trains in the timetable and the searched train slot.
Figure 1: Parameter dialog of slot search engine.

The result of a search can be displayed in two ways. Both views can be used in principle by planners and dispatchers for their work. Figure 2 illustrates the network view, showing the resulting route in the network. In this example, the task was to find a slot from Löhne (HL, red arrow) to a station near Aachen (KAW, green arrow). The feasible path in the network is highlighted in yellow.
Figure 2: Network view.

Figure 3: Timetable view.
Figure 3 shows the timetable view common in Germany. In other countries (e.g. UK) the time and way axis are changed (a button can change the mode in RailSys). Again, the yellow line indicates the slot found by the slot search engine. In addition, the occupation time of blocks can be seen.

3.2 Algorithm and performance

The database of the slot search engine is closely related to the internal RailSys data model. On the basis of RailSys microscopic infrastructure and the existing timetable, the available time and occupation slots on all edges and blocks in the entire network are calculated in a pre-processing step. The result is all available corridors within the timetable.

The feasible slot is searched simultaneously in time and in space considering all available slots within the timetable. The search engine works on the basis of the “Dijkstra” algorithm. According to the boundary conditions, the algorithm searches for a series of linked corridors, matching the time and space parameters. The corridors are developed taking into account the start time, running time, stopping patterns, occupation times and dynamical parameters of the train type.

According to the parameters, the search criteria and the result, can be modified. For example, it is possible to allocate way-points to force the algorithm to include those points in the feasible path. Varying the parameters of the cost functions can give results for different applications. For example if the user needs a free path for a fast freight train the most important aspect is to get it to its destination as quickly as possible. For this application the user can increase the cost for the stopping time and the running time. In this case the algorithm searches a fast train slot that can have a rather delayed starting time. Otherwise, in a case where the starting time is fixed, the user might increase the cost of the starting time and lower the costs of stopping time and running time.

The test computations using the Nordrhein Westfalen project (approx. 10.000 km of track and 8.000 trains/24hours) showed, that a response time of about one minute for one search task throughout that network is possible. However, the algorithm will be improved over time as usage increases.

4 Strategic network modelling

The macroscopic simulation model NEMO [2], developed at IVE in cooperation with the Austrian Federal Railways (ÖBB) since 1999, is a strategic planning tool for the evaluation of infrastructure and operational issues. Based on a macroscopic network, NEMO models the complex interaction between network infrastructure, railway operation and transport demand.

NEMO provides a way to efficiently evaluate different production and infrastructure scenarios in passenger and freight traffic. Transport supply can be optimised based on demand and capacity. Thus, the model supports efficient use of investment funds and an economic evaluation of planning scenarios can be used to identify saving possibilities. The basic structure of NEMO is shown in Figure 4.
In addition to this, NEMO can be used as a simulation tool either to support infrastructure operators in detailed transport and network planning or to consider the result of changes to the overall transportation market. Strategic tasks like evaluation of railway infrastructure issues and determination of the network traffic volume based on the demand for transport services can be performed. Furthermore, effects of altered production and operational concepts on the network traffic volume can be examined.

The communication between RailSys and NEMO is realised via a program-internal interface. The microscopic model RailSys acts as a server-application in the background, while the macroscopic NEMO model requests automatically all network infrastructure and operational data.

For any interaction to take place between the two programs, RailSys has to be started as a server application either running on a network computer or in the background on the local machine. The local server program can be automatically launched by NEMO, which acts as a client, asking the server to send the requested data. This interaction of both programs is realised using socket-communication via a TCP/IP connection. All information is exchanged as XML-formatted data packages. The four main tasks performed by this interaction are automatic network abstraction, generation of model trains, calculation of running times and determination of minimum headways [4].

5 Application and perspective

The fields of application for the slot search engine can be described in the following areas. The aim is to provide a very flexible set of tools for the short term planning tasks as well as a methodology for an automated timetable
construction. The applications of each step are the basis of the following process, n.b. the timetable generated by the automatic timetable construction can be used as input for the following timetable construction. All application stages support the allocation and dispatching of vehicles to train runs as well by providing long term or ad-hoc timetables [5]. Therefore, interfaces between RailSys, NEMO and Dispo have been developed [6].

5.1 Long term planning

For the long term planning the interaction between RailSys, NEMO and the slot search engine is an interesting perspective as described in the article. The potential to develop an automatic timetable construction on the basis of a ranked slot search can be seen here, and has been tested already internally.

5.2 Timetable construction

The task of the timetable construction consists in general of two main activities: first to plan new slots for passenger and freight trains, and integrate them into the existing timetable. The second task will be the re-routing and rearranging of existing conflicted trains. Both tasks can already be performed with the slot search engine.

5.3 Short term planning and ad hoc dispatching

The slot search engine will support the short term and ad-hoc planning as well. Due to the reduced available time, the slot search engine will help to find feasible slots in a short time taking into consideration even daily changes of parameters (train characteristics, temporally speed restrictions etc.).

The RailSys technology could be used in a railway control centre to simulate on the basis of the current traffic situation over the next couple of hours in order to provide assistance with dispatching decisions.

5.4 Internet access and client server technology

The RailSys server technology provides an internet access to the RailSys environment. This technology could be used for third parties to calculate running times or to search for possible slots without having direct access to the infrastructure and timetable data. It could be possible to hide confidential information for third parties so the system could be used to reduce the planning process for a timetable in a competitive train operator environment. Third parties even could book the slots via the internet.

6 Conclusions

The paper provides an overview of the possible usage of the RailSys slot search engine developed by RMCon and IVE for railway timetables in a microscopic detailed infrastructure environment. In combination with the proven synchronous
simulation, both techniques can be implemented and used in flexible planning and operational software systems for railway and train operating companies, ministries, regulator authorities and consulting companies.

The parameters, algorithm and methodology provided by the paper demonstrate the quality and performance of the solution and indicate possible enhancements for the future. Based on the well known Dijkstra algorithm, the slot search engine is another example that feasible and well performing solutions can be developed in a reasonable time.

References