Handling of railway operation problems with RailSys

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Introduction

To plan future system requirements and to evaluate the impact of these requirements on the railway system, efficient computer aided tools are needed. The complexity of the railway system, combined with the number of boundary conditions, results in a very large number of possible variations. Therefore, several alternatives have to be investigated which extends the duration of the whole planning process. Additionally the costs for e.g. infrastructure extensions of the network are very high and the accurate planning is the key to prevent investment mistakes.

The uncertain estimation of future development of public transport traffic raises the number of variables. The intensity of train services can change between two timetable periods while the building of infrastructure needs in general several years.

To enable the detailed planning of infrastructure, timetable and the use of vehicles for several variants and alternatives, the system RailSys has been developed. The software includes accurate tools for running time calculation, infrastructure mapping, timetable-construction and evaluation and the planning of vehicle rosters.

RailSys uses a microscopic description of the real world in the model to reduce the risk of wrong decisions based on an inexact planning. The planning process has to take into consideration, that investing in railway infrastructure or vehicles is in general a long-term investment. On one state of the art computer, it is now possible to model the whole German railway network (approx. 40,000 km of track) with approx. 30,000 trains in RailSys.

1 The system architecture of RailSys

To fulfil the demands of customers, railways need to optimise their timetables and their capacity of tracks and stations. The planning of railway infrastructure or future timetables is based on the existing network and the running times in the future. To calculate the number of necessary vehicles and to consider empty train runs a vehicle roster plan has to be calculated. The completed timetable is simulated to demonstrate its robustness and stability in case of disruptions. Finally the results have to be evaluated to obtain a ranking of the alternatives. Figure 1 shows the system architecture and data flow.
Architecture of the planning environment *RailSys*

**Infrastructure modelling**
To model the existing infrastructure and to build up infrastructure variants, the *RailSys* System includes an infrastructure editor. This editor allows the user to model the whole network in the computer with the accuracy of one meter. The mapped infrastructure contains information about track parameters like gradient, max. speed, etc.. The location of points, signals, stations, stopping points, speed indicators, platforms and tracks are considered. The infrastructure data can be edited manually on the screen. Alternatively, the infrastructure data can be imported with interfaces from other data sources. Signalling systems like ETCS (European Train Control System), radio controlled operation or ATC/ATO (Automatic Train Control / Operation) can be edited additionally.

**Train run computation**
The exact calculation of running times and energy consumption can be performed with *Dynamis*, a tool to simulate train runs of all train types on the existing or to be planned infrastructure. *Dynamis* considers the traction force vs. speed diagram of the locomotives, as well as the weight and length of each vehicle. It includes an interactive tool to get an exact overview of the calculated train run and to modify all input data interactively. Additionally, energy saving driving strategies, the computation of the location of signalling infrastructure or the check of the alignment of the track can be undertaken.
Timetable construction and simulation
The results of the running time calculations can be transferred into the timetable construction phase done with Simu++. Simu++ includes all necessary information of the infrastructure such as gradient, speed restrictions, block signals (various signalling systems), platforms, points and stations.

The handling of large railway networks consisting of many lines and stations is supported by a modular set up of the railway network. Every line in a large-scale network can be planned and simulated independently. Any lines can be joined to a network at any time during the planning process and can be separated again Afterwards. For example, the network of a railway company can be separated into several local areas or sectors (i.e. suburban areas and the lines between these areas). Trains running on more than one line can be scheduled by supervising planners. Simu++ indicates inconsistencies such as unfeasible connection times and differing transit tracks in stations for these trains.

The signalling system moving block (specified by the ETCS standard) is implemented. The model supports the principles of the running in absolute or relative braking distance. Trains using this system can be mixed with trains using traditional signalling systems. This is supported throughout the whole program system i.e. timetable construction and simulation.

Vehicle roster planning
The main task of the program is the optimal allocation of locomotives in large networks. Typical applications are the roster planning of several hundreds of different series of locomotives according to given boundary conditions (e.g. reversing times, compulsory connections or track slot prices). The main target is to minimise the number of locomotives and to reduce the number and length of empty train runs. The planning of the maintenance task is integrated. Additional parameters, for example the prices of track slots, can be used for the computation.

Performance Evaluation
To evaluate the impact of infrastructure and/or timetable alternatives the Performance Evaluator PE has been developed.

This tool serves for the evaluation of the performance of the simulated operational program. The main bases for this task are the delays of trains during the simulation, which are statistically prepared and analysed. The results of the simulation can be displayed as performance of the whole network, for lines only or in stations.

2 Planning Process working with RailSys
For most questions concerning railway operation and railway infrastructure it is possible to use a standardised planning process working with RailSys. A standardised planning process is shown in figure 2. The planning process is mainly characterised by taking into account assumptions for variants, which usually lead to an increased number of variants. Different expectation values for infrastructure or service measures can be determined by the iterative procedures of variant definition, simulation and evaluation.
Standardises Planning Process Working with **RailSys**

**Data collection**
In a first step, the original data for the examination is collected. It includes the necessary details concerning the infrastructure (tracks, turnouts, positioning of signals, speeds, gradients etc.), the rolling stock characteristics, and the operational program (timetable). The operational program is based on a multitude of train types. A reduction of the variation of train types is undertaken due to the simulation purposes by combining train types with the same or similar dynamical characteristics to model train types. Furthermore, delay reference values are to be registered or determined as basic values for the simulation. The referring modules of the program system RailSys further compute the determined basic values.

**Model calibration**
When all relevant data is implemented into the model, the model calibration starts. In general, two approaches for the calibration are possible, that derive from the planning task. For examinations that base on an existing infrastructure or an existing operational program, a model calibration can be made referring to the current operational situation. For examinations that base on a planned infrastructure or a planned operational program, usually a calibration can only be made by controls of likelihood or by comparisons with other, independent calculations (e.g. running times).
**Status quo definition**
After having calibrated the model, a zero-variant, the status quo, is projected. In case of the further use of the existing infrastructure or the existing operational program, the variant on which the model is calibrated can be used as the status quo variant. The statistical characteristics of the status quo variant serves as an evaluation basis for other variants in the remaining planning process.

**Development of alternatives**
The further variants derive from the variation of the examined infrastructure or timetable parameters. The number of variants usually depends upon the complexity of the examined area. In an ideal case, a matrix can be derived that consists of the different combinations of infrastructure- and operational program-constituents.

**Simulation of alternatives**
After the definition and construction of examination variants, a simulation takes place. Here, two simulation approaches have to be distinguished. On one hand, a multiple simulation based on statistical introduced disruptions into the timetable can be applied. In general, 50 to 100 timetables will be disrupted (e.g. with a variation of stopping times) and simulated. On the other hand, it is possible to compute single simulations in frames of case studies without the influence of any appearing input delays. In both cases, delay developments can be disposed as the simulation’s result.

**Statistical evaluation**
The performance characteristics as a result of the simulation can be determined either exact for a train or for model train types at any station. Declaring a signal or any other point of interest in the network as a “station” enables the user to investigate every location in the network precisely. Furthermore, the delay developments can be summarised by statistical characteristics and thereby be compared. The following chapters will give further information concerning the values of the statistical evaluation and the application of these values using this standardised planning process.

**Comparison and rating**
By utilising the statistical characteristics like the delay development, a comparison of the effectiveness of single measures concerning the infrastructure or the timetable can be performed. Usually, the status quo variant is taken as a reference basis, so that a relative comparison of variants can be made. If the examined measures based upon known starting parameters and the model calibration proved that the model delivers safe results, the results indicate a to-be-expected performance of the simulated variant.

**Decision**
The last step of the presented planning process is the decision-making on the basis of the computed variants. Therefore, the weighting of each variant has to be made by the planner, concerning to their own notion. If the simulated variants should not lead to an acceptable result, further variants can be defined and later be simulated, until optimised results are approached by means of an iterative process.
3 Characteristic Values

The simulation of railway operations on a given infrastructure provides the user with characteristic values. The following figure illustrates some characteristic values as an example:

**RailSys Characteristic Values**

**Arrival and Departure Delays**
**RailSys** computes delays considering the arrival or departure of trains at each station in the network. The evaluation can be based on different or all train types in a station. The changes of the arrival or departure delay from station to station can be displayed in a network graphic.

**Additional Delays**
The in- or decrease of delays (additional delays) between two stations can be shown in a graphic. This result can be used to identify critical sections and bottlenecks in the network (e. g. insufficient design of block sections) to run the timetable.

**On Time Running (OTR) Performance**
Each station can be evaluated in respect of the on-time-running of train types. A timetable can be rated based on the percentage of trains with a delay less than a certain value, e. g. 95 percent of all trains are delayed for less than 180 seconds.

**Number of Delayed Trains**
The number of delayed trains and the delay per delayed train can be computed for every station. These results can be used in “What-If” scenarios to measure the impact of the breakdown of a locomotive or a single disruption of a signal.
Number of Operational Manoeuvres

RailSys counts the operational manoeuvres in each station during a simulation. An operational manoeuvre, e.g., extension of the stopping time or change of a track in a station, may be useful to recover a delayed timetable.

Block Occupation

The block occupation by trains during the simulation of a timetable can be used to describe the statistic use of each block in the railway network. Furthermore, the block occupation can be used to describe timetable conflicts.

Timetable

The timetable provides a wealth of statistical information. The following list can be considered as an example:

- Number of trains and train types,
- Train kilometres,
- Number of trains connecting stations in the network,
- Running time between stations in the network.

4 Practical use of the characteristic values

RailSys provides a huge amount of various characteristic values. These values are the input for analyses, which in the following paragraphs will be described.

Verification of a theoretical technical capacity

The theoretical technical capacity of a railway infrastructure can be defined as the number of train runs in a certain time scale on that infrastructure.

Analytic methods use a prognostic factor for a given timetable on an infrastructure to calculate a numerical value [Trains/h] to represent the capacity of the infrastructure. The prognostic factor that describes the future demand extends the number of trains of the given timetable linear, not regarding the mix of train types. Therefore, the ratio of passenger and freight trains stays exactly the same. The capacity of the infrastructure is based on the definition of the length of “waiting” queues and the summation of additional delays.

Comparing with the analytic methods RailSys does not calculate a single numerical value describing the upper level of the capacity of an infrastructure. However, with RailSys a defined timetable will be constructed and simulated. The quality or the capability to recover from delays of that timetable can be evaluated on the bases of the above-described characteristic values. The results delivered by RailSys offer a much wider scope for the evaluation of scenarios. The user of RailSys can tailor the investigation according to the demand of the client. Results are much more comprehensible in any detail.

In general, a satisfactory quality of the railway operation on an infrastructure can be established, if a delay coming into that system from outside is not increasing in the system. A good quality can be established, if the delay coming into that system can be reduced inside the system. The capacity limit can be evaluated iterative by increasing the number of trains and simulating the new timetables. This capacity is based on an exact timetable including the mixture of passenger and freight trains in that timetable.
**RailSys** provides all necessary data to calculate a numerical value of the upper level of the infrastructure capacity based on a realistic mix of trains. During the simulation, all block occupation times and all conflict times will be computed. This time data can be provided as the input of a standard analytic method.

**Verification of a theoretical commercial capacity**

The commercial capacity can be defined as the performance of a timetable on an existing infrastructure within predefined limits (e.g. to obtain a 95 percent OTR in a railway system). The commercial capacity becomes more and more important with the increasing number of regional train operators in Germany and other countries. The states and cities in Germany are responsible for the tender and the operation of the regional passenger traffic. Past experience shows that the OTR was an important criterion of the timetable quality.

**RailSys’ OTR evaluation** (summation of delays of different train types at each station) provides a very well established value to check and compare the planning with a demanded quality. The OTR evaluation can be adjusted to single stations, lines or even the whole network.

The OTR as a result of the simulation provides an excellent opportunity to alter and optimise the planning of a timetable, the implementation of new infrastructure or the investment in to new rolling stock. The planning process involves the network provider, the regional train operators and the states. Therefore, the OTR may be a criteria of an arbitration between different expectations. A weak performance in the real world (including delays and disrupted operation of the timetable) may cause penalties.

In English speaking countries (e.g. Australia), the OTR is an important characteristic value to evaluate the performance of a timetable and the capacity of an infrastructure.

**Analyse of bottlenecks**

Analysing the bottlenecks in a railway network, the OTR values and especially the time of the block occupation can be used. The OTR values enable the identification of stations, where the operation of the timetable on the given infrastructure may cause delays. The analysis of the block occupation and the block occupation time identifies local bottlenecks in a station or on a line. The local bottleneck may be a single signal or a point.

**Analyse of the timetable**

The conflict free and robust timetable can be evaluated regarding traffic aspects. For example, the number of seats in passenger trains can be computed for different relations, train types or times (peak hour and off peak). Additionally, the travelling times and the correspondences are important criteria to develop a timetable and to derive necessary improvements of the infrastructure.

**Energy optimised Timetables**

The integration of further software packages into **RailSys** (e.g. Dynamis with sophisticated running time and energy consumption calculation algorithms), enables the optimisation of timetables regarding the energy consumption. In an iterative process, the infrastructure may be adopted based on the energy optimisation.
Planning of Power Supply

RailSys includes an interface providing the necessary information for external power supply computations.

5 Applications

In the past, the program system RailSys has already been applied for various projects at IVE and RMCon. The examinations included long distance railways, complex networks and urban and city railways. Thus, RailSys was applied successfully in the following projects:

- High Speed Line Cologne-Rhein/Main
- High Speed Line Sydney Canberra, Australia
- City railway Munich, Cologne, Sydney, Melbourne
- Network Simulation Nordrhein Westfalen, Berlin

The exceptional challenge within each project was mainly to analyse the different and specialised frame conditions of the various national and international railway systems and to successfully integrate them into the program system RailSys.

For further references please see [4] and [5].

References


[5] Website of IVE, University of Hanover [www.ive-uni.hannover.de](http://www.ive-uni.hannover.de)