Timetable stability - using simulation to ensure quality in a regular interval timetable

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Abstract

A regular interval timetable is characterised by train services that run in a fixed pattern, e.g. every 60 minutes. All trains of the pattern depart at the same station at the same minute during the whole day. To enable the passengers to reach all stations that cannot be connected by direct trains there are connections between several services at network nodes. The connection times are often short (generally less than 8 minutes). Therefore, there is a strong demand for a very good on time running in the network. Otherwise delays will be transferred between trains that do not interact directly or connections for passengers are lost.

The 2003 passenger timetable was constructed from the concept worked out by North Rhine-Westphalia's ministry of transport that is commissioner for the regional train services. This regional passenger concept had approx. 5,300 passenger train runs per day. It considered all political requests regarding service frequency, stopping patterns, etc.

1 Introduction

The 2003 regular interval timetable in North Rhine-Westphalia is designed to meet the following objectives in public transport politics:

- Increasing the services in regional and long distance passenger services
- Optimising the on-time-running of passenger services
- Optimising track bound freight services

Railway passengers demand short journey times and convenient connections between different services. To ensure the planned arrival at the destination the

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on-time-running level must be high. This requires a robust and reliable railway operation. To recover from delays reserves like running time allowances and buffer times between train runs have to be considered in a sensible way.

A regular interval timetable has network wide dependences. On the one hand there are boundary conditions from the passenger flow, like connections between different trains at the network nodes. On the other hand there are operational constraints like track occupations from several trains within a short period of time. This becomes even more significant where fast and slow passenger trains and freight trains have to share the same track sections. These interactions need to be handled by an integrated examination of the whole network.

The experiences during the first phase of the regular interval timetable in NRW (1998) showed that the robustness and reliability of the timetable was dependant on good planning. Therefore, the second phase of the timetable concept was investigated by a detailed timetable simulation before the services started in reality.

This investigation performed by Rail Management Consultants Ltd. (RMCon) from Hanover, Germany [1] with the help of the railway simulation system RailSys. The main aim was to find out where operational weaknesses are and how they could be solved before the timetable was set into operation. The results showed that the timetable would be robust under the given circumstances like modern rolling stock, etc. As some of these conditions could not be met in reality further investigation was needed with regard to the changed circumstances.

RMCon has developed the Timetable and Infrastructure Management System RailSys to perform operational investigations on large railway networks. Timetables can be constructed regarding the exact block occupation times of each train run in a detailed planning process. In the following simulation all train runs of the constructed timetable are modelled for the whole network. The consequences of delays obstructing other trains are modelled. This allows judging of interactions between different parameters such as delays, rolling stock parameters and signalling equipment.

2 Initial situation and objectives

The original 2003 timetable concept was based on several boundary conditions that could not be met at the beginning of the timetable period. On the one hand modern rolling stock was expected which has higher velocities, higher acceleration rates and allows shorter dwell times because of larger doorways. On the other hand several stops needed longer time than scheduled. These circumstances caused delays in the regular operation and the on-time-running performance was not as good as expected.

The on time running performance measured in real operation did not meet the simulated figures from the investigation of the 2003 timetable concept done by Rail Management Consultants Ltd. (RMCon) from Hanover, Germany. There was the need to improve the database regarding the changed boundary conditions. This led into a new investigation of the whole NRW railway network. The investigation to increase the on time running of the 2003 timetable

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of North Rhine-Westphalia, Germany, was commissioned by Germany's largest regional train operator DB Regio AG.

In the timetable there are a lot of connections between different regional services as well as between regional and long distance services. This requirement and a high frequency of trains, creates a lot of dependencies between the train runs. Problems in one network area are carried on to other areas of the network. The aim of the detailed investigation of the 2003 timetable was to find solutions for improving the on time running by adjusting the timetable to the changed boundary conditions. This included e.g. adaptations of scheduled running times and dwell times to reduce delays. The political requests (service frequency, stopping patterns, connections, etc.) in the timetable had to be kept up.

The investigation's aim was to find solutions to solve the described problems within the planned timetable concept. If alterations in services were needed the basic timetable concept always had to kept up. The results should prepare the registration of train paths at the German railway network provider, DB Netz AG.

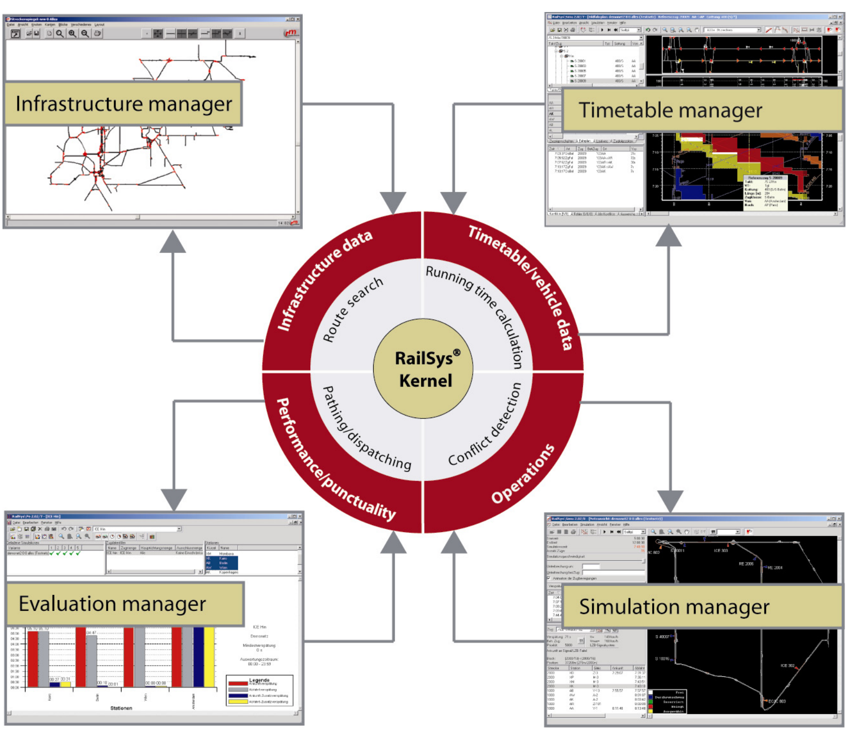

Figure 1: Timetable and infrastructure management system RailSys.

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3 Investigations to improve the on-time-running of the 2003 timetable in North Rhine-Westphalia

3.1 Work packages

Within the examination the following work packages have been realised:

- Establishing the model (timetable and infrastructure data import, adjustment of used rolling stock)
- Evaluation of services with rolling stock and dwell time problems
- Construction of timetable scenarios to solve problems
- Simulation of two timetable scenarios to investigate the use of increased scheduled dwell times
- Delivery of timetable modifications to DB Netz AG to be considered in the construction of the working timetable

3.2 Timetable and Infrastructure Management System RailSys

The evaluation of the 2003 NRW railway timetable was done with the Timetable and Infrastructure Management System RailSys. RMCon and the Institute of Transport, Railway Construction and Operation (IVE) of the University of Hanover, Germany [2] developed this software for rail bound traffic. RailSys allows a very precise computer aided modelling of operational procedures in railway networks. All relevant safety systems and operational conditions are included. It is designed with the special ability to model large and complex railway networks on a microscopic base.

The software runs on a standard Microsoft Windows PC as well as Unix/Linux Computers. The system architecture of RailSys software is shown in Figure 1.

3.2.1 Input data

The model needs the following input data:

- Infrastructure
  - Track layout (length, gradients, turnout locations, etc.)
  - Safety system (signal positions, signalling system, route setting times, etc.)
- Operation
  - Vehicle data (traction units, train length, train mass, etc.)
  - Timetable data (arrival and departure times, planned running times, platforms used, etc.)
- Simulation
  - Delays (entering the system late, dwell time delays, etc)
  - Dispatching rules (alternative platforms, priorities, etc.)

3.2.2 Timetable construction and simulation

Timetables can be constructed with RailSys' timetable manager. It calculates all block occupation times for each train run and automatically detects all conflicts between train runs across the whole network. The user can solve these conflicts

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interactively with the help of an automatically generated timetable graph. All construction rules, like margins between trains, and running time reserves, such as general allowances or allowances for engineering works, can be displayed during the construction. Figure 2 shows RailSys' graphical user interface for the timetable construction.

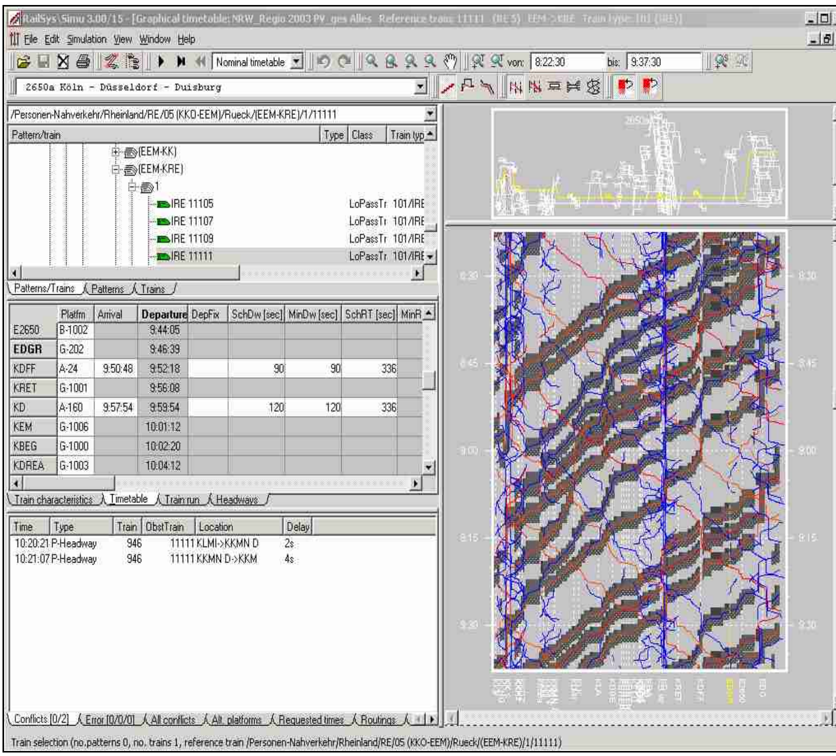

Figure 2: RailSys timetable construction user interface.

Creating a conflict free static timetable does not suffice to prove whether a timetable will result in satisfying operational quality, or will generate a delay-burdened operation that satisfies neither the operator nor the passenger [3]. Only an operational simulation can verify the operational program substantially and evaluate the operational quality before the timetable is launched.

Therefore, in addition to the timetable construction, the operational simulation is the substantial component of RailSys. To check the robustness of an operational program several timetables representing a series of operational days are overlaid with various automatically generated perturbations (multiple simulation). These perturbations are normally based on real operations' experience and are represented by probability distributions. Different distributions can be implemented for each train run at each station, or at other

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places in the network where perturbations can occur. Delays can also be added to trains as they enter the simulation area.

In the multiple simulation each train run gets different perturbations from its distribution on each operational day. Integrated routing algorithms simulate the actions traffic controllers would take to influence the disrupted traffic flow. Thereby signalling rules and priority strategies are considered. Other possibilities of delay transfer are reversing or connected trains. If a train turns around at its ultimate destination, delays are transferred to the next train in the opposite direction. There can also be connections between different services in the network nodes representing trains held back to ensure the passengers' flow from another train. Running time or dwell time allowances are taken into account, reducing the delays caused directly by perturbations or indirectly by delayed train runs.

After the simulation, the average delays of all train runs over a period of several days or weeks are evaluated. This shows where operational problems exist in the network and visualises possible bottlenecks. If problems and/or bottlenecks occur there is the option of reducing the timetable requirements, or increasing the infrastructure capabilities. After the delay evaluation an iterative process starts to optimise the combination between the requested timetable and the required infrastructure. Additionally on-time-running figures and the percentage of kept or cancelled connections can be evaluated.

3.3 Database

The investigation area covers the whole railway network of Germany's state of North Rhine-Westphalia. The infrastructure and timetable data was delivered by DB Netz AG in digital format from the currently used timetable construction tool RUT. The data covers all details of railway infrastructure as signal position, turnout locations, gradients, speed limits, etc.

Because of the complexity of the network the infrastructure data in RUT had to be divided into 12 independent partial networks. This data was imported into RailSys and connected to one network free of redundancies as shown in Figure 3. The 2003 timetable data was also imported into RailSys from the RUT system. This data was completed with extra information about platform working in the stations and reversing connections at the trains' final destinations and the currently used rolling stock.

3.4 Timetable construction

To construct a network-wide conflict free timetable as a base case, the different data sources had to be merged. This complete database allowed working out concepts to solve the operational problems. Therefore, several scenarios were constructed regarding the following problems:

- Extension of scheduled dwell times in highly frequented stations for fast regional trains (RegionalExpress RE) within the existing timetable
- Alternative timetable concepts for services using rolling stock with speed restrictions to reduce delays from extended running times

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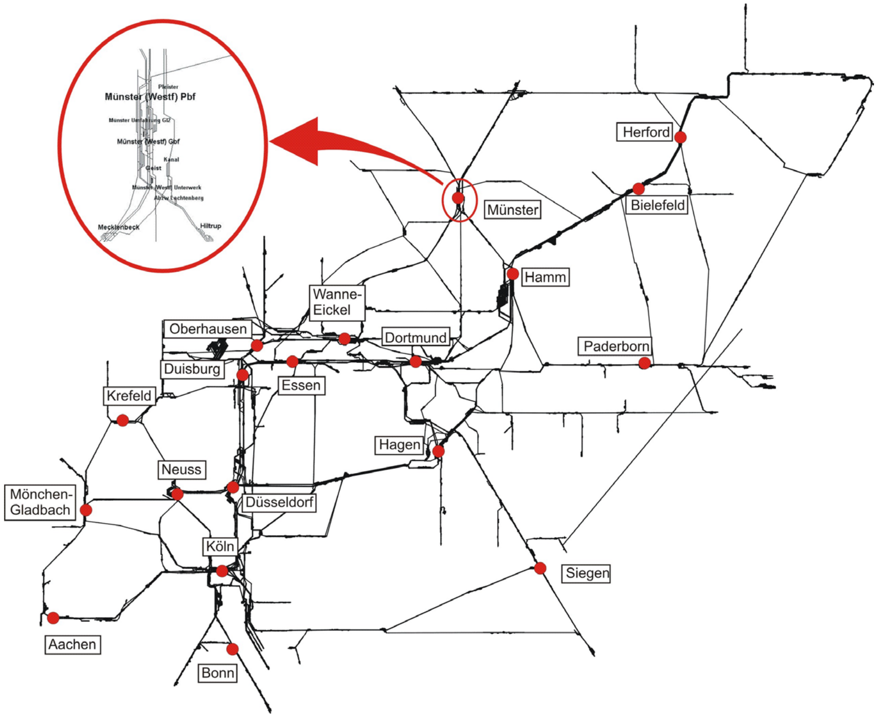

Figure 3: Entire railway infrastructure of North Rhine-Westphalia in RailSys.

RailSys allows a very efficient timetable construction. If conflicts between trains occur because of alterations in the timetable they are detected on the whole network simultaneously. These conflicts can be solved using different platforms in stations or adjusting train runs following each other on the line. The original arrival and departure times from the imported timetable are available in RailSys as requested times. This allows analysing the deviation of the newly constructed train run from the original train run. To create a complete 24-hour timetable the trains can be constructed in a pattern structure. All trains of one service pattern can be modified in parallel.

The whole timetable construction is done with regard to valid timetabling rules used by the DB AG. These rules cover basic running time allowances, special running time allowances for engineering works and buffer times between trains to avoid delay transfer.

3.4.1 Dwell-time extensions on RegionalExpress trains (RE)

To ensure on-time departure at stations with higher passenger demand the scheduled dwell times on some fast regional trains (RegionalExpress RE) had to be extended. The longer dwell times extended journey times between the network nodes. This might cause conflicts with following trains on the same line section. Also connections to other services in the network nodes can get lost.

This led into necessary alterations in the timetable. The timetabling rules of the DB Netz AG cover margins between train runs and running time allowances for engineering work, etc. If there are extra reserves in the timetable they can be used to recover from the scheduled dwell time extensions. If there are no extra reserves some station stops have to be cancelled. Another possibility is to alter other conflicting trains as well to ensure a conflict free timetable. An example of scheduled dwell time extensions can be seen in Figure 4.

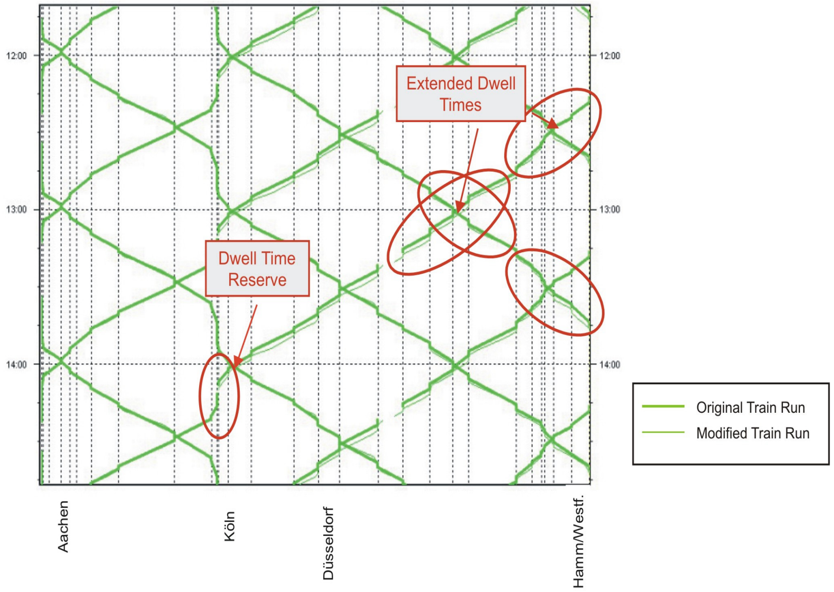

Figure 4: Dwell time extensions on fast regional service (RegionalExpress).

The results with all altered train runs were handed over to the DB AG to be considered within the alteration of the working timetable.

3.4.2 Timetable concepts due to speed-limited rolling stock

In 2003 several regional services were taken over by modern electric multiple units. These units are designed for a maximum speed of 140 km/h. Due to braking problems they were limited to travel at 120 km/h.

This speed limit produced on some services scheduled for 140 km/h very high delays. To ensure a better on time running even with the slower vehicles timetable alterations were discussed. In two areas in North Rhine-Westphalia the required adaptations caused alterations in the timetable concept.

To find the best solutions several concepts were investigated by RMCon during a three-day conference with DB Regio. In this meeting running times, free train paths and the compliance with planned connections were evaluated. Due to the network wide conflict resolution in RailSys and the ability to

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construct a whole-day service pattern at once final concepts could be worked out very fast.

An example of what happens to the service when it runs at lower speed without alterations in the timetable was evaluated with the simulation (Figure 5).

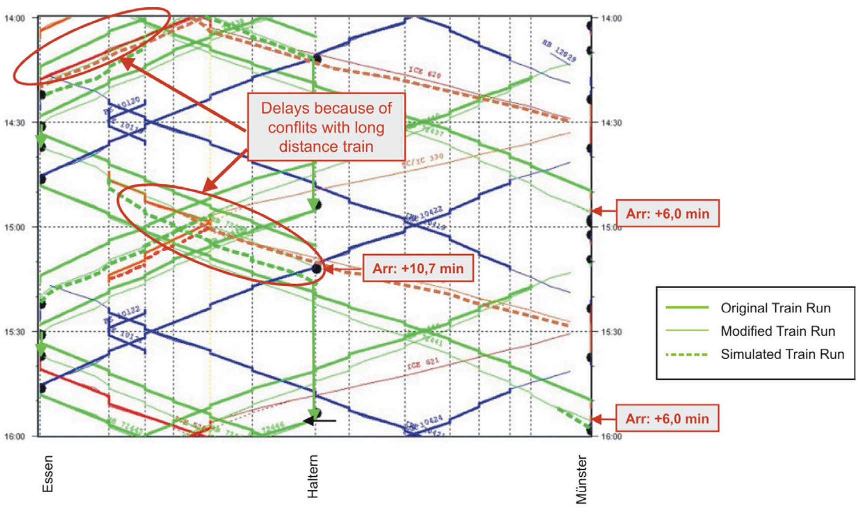

Figure 5: Delays caused by speed limited rolling stock and disruptions with other trains.

This example shows that the train gets delays from the speed limit and additional delays due to hinder by other trains. The delay is compared to the originally scheduled times. The total delay rose up to 10 Minutes at the terminus.

To run the service scheduled at lower speed several alterations had to be done on a highly occupied line section. The alterations could be done sustaining the 2003 timetable concept with all stops and connections.

4 East-Westphalia network

A second area with speed limit problems was the region East-Westphalia around the cities of Hamm/Westf, Bielefeld, Paderborn and Münster. As there are several services using the above described speed-limited train sets, the required alterations led into a completely new timetable concept (Figure 6).

This concept was worked out by DB Regio AG. RMCon investigated whether the services could be constructed conflict-free regarding the remaining passenger traffic.

In addition to the alteration of the regional services' train paths the complete platform working in the network node Hamm/Westf. had to be rescheduled. This station is characterized by a lot of services arriving and departing at the same time to ensure connections.

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On several lines the requested stops had to be allocated to other services. Also different rolling stock with higher velocity was used for several services to keep the requested running times between the network nodes. In some areas the planned concept concerning stops and connections had to be altered.

This altered network concept was basis for a discussion with the ministry of transport of North Rhine-Westphalia who worked out the original concept.

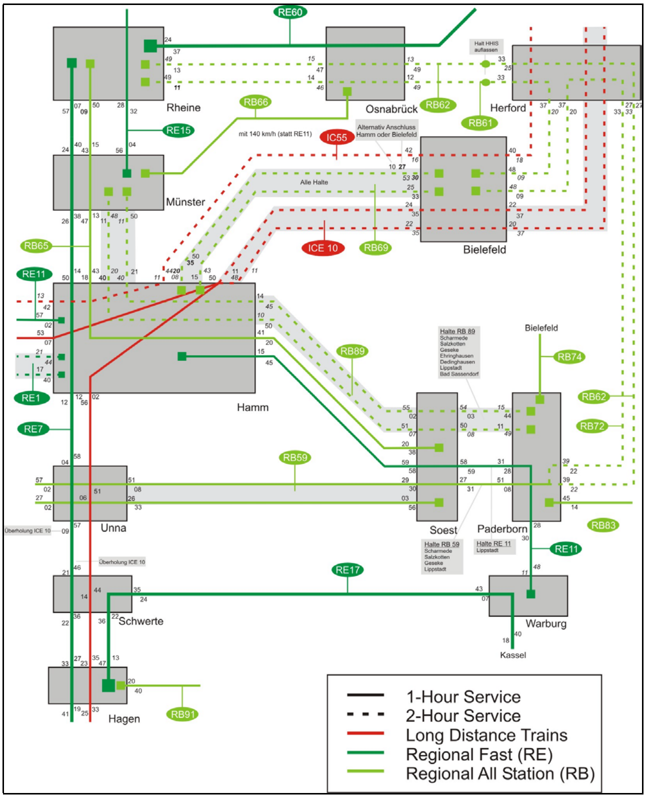

Figure 6: East-Westphalia network investigated with RailSys.

4.1 Simulation of improvements

In the timetable concepts worked out with RailSys, one topic was the extension of scheduled dwell times to cope with higher passenger demand in selected stations. This was evaluated for all fast regional services (RegionalExpress RE) in NRW. One result was that in some cases the extension could be done without changes in the timetable concept. In other cases adaptations were needed to sustain connections with other services.

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4.1.1 Dwell-time extensions on RegionalExpress trains (RE)

The impact of extended dwell times on the on-time-running performance was investigated with the help of RailSys' operational simulation. Therefore, an investigation of passenger flows was done to categorize stations into highly, medium frequented and lowly frequented stations. In the simulation the trains got dynamic dwell time delays in these stations. The delay distributions are based on general figures provided by DB Netz AG because an evaluation of real delay figures was not possible during the project.

The simulation results were used as a basis for discussions about the timetable concept with the commissioner of regional services, the ministry of transport of North Rhine-Westphalia.

To examine the effects of extended scheduled dwell times two timetable scenarios were simulated and the results were compared:

- Scenario 1: Original timetable with given dwell times
- Scenario 2: Adapted timetable with extended scheduled dwell times

In both scenarios the same delay distributions were used and the minimum dwell times were similar. The extended scheduled dwell times imply higher dwell time reserves to recover from delays.

After simulating both scenarios, the evaluation of the resulting delays and on-time running figures was performed. The results were evaluated in two different ways. The major part was to examine the operational quality. This procedure was focussed on the trains' average delays. Operational quality is defined as 'good' if the trains do not have increasing delays within the examined area. It is considered 'insufficient' if the trains' delays increase within the investigation area.

The second evaluation was the comparison of on-time-running figures in both timetable scenarios. The on time running measured in selected stations is a criterion for the service quality defined by the commissioner of local transport services and the railway operators. Trains that are delayed less than 5 minutes are considered on time.

4.1.2 Operational quality

The evaluations regarding the operational quality were done separately for long distance passenger trains, local passenger trains, suburban trains and freight trains. The results of both scenarios were compared to detect changes within the operational quality.

The examination of the average delays gives hints where operational problems exist and thereby helps locating bottlenecks within the network. The first analysis was done macroscopically with evaluations of delays within the network. For areas or lines with higher interest detailed evaluations have been executed subsequently. Arrival and departure delays dwell time delays or delays due to dispatching actions were evaluated separately.

An example of average delays evaluated on a RE-service can be seen in Figure 7.

In both scenarios the service shown has increasing delays on its route. Based on the definition the operational quality is insufficient. The comparison of both

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scenarios shows that with extended dwell times the average delay along the whole train run is lower than in the original timetable.

After evaluating all adopted lines the evaluation showed in which stations the dwell time extension had positive effects and in which stations the dwell time extension achieved no improvement.

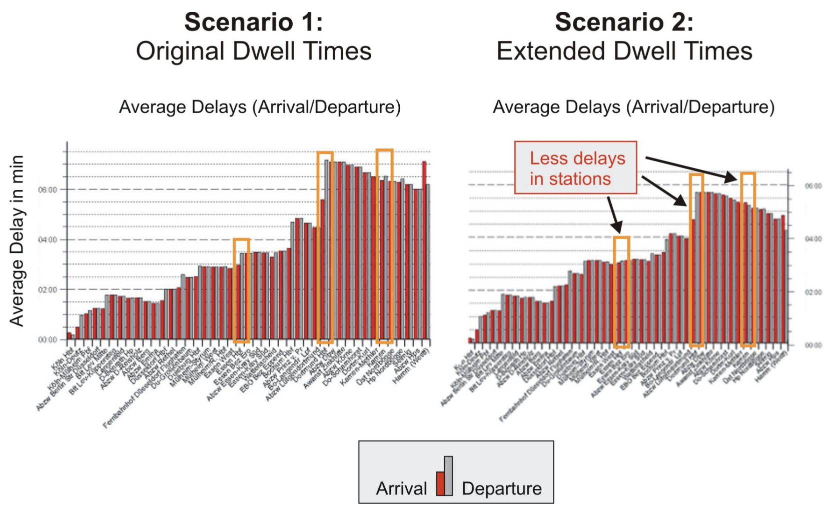

Figure 7: Example of an evaluation of operational quality (average delays).

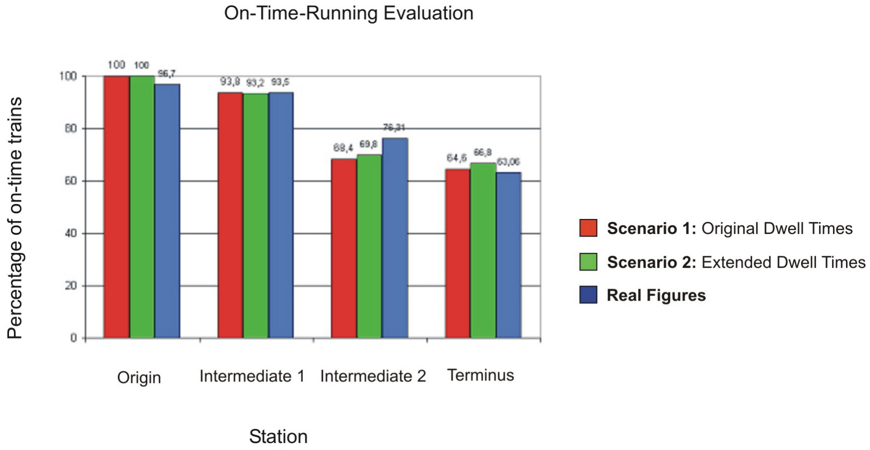

Figure 8: Example of an On Time Running comparison.

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4.1.3 On-time-running

Analogous to the evaluation of the operational quality, comparisons have been made between the investigated on-time-running figures of the two scenarios. The results were then compared to on-time-running figures from the real operation.

A comparison between the simulated on-time-running values in Figure 8 and the real values allows a validation between simulation and reality. A simulation working with general assumptions concerning the delays cannot provide exactly the same figures than real operation. But this example shows that the simulated on-time-running values in scenario 1 were generally quite close to the real figures. The improvement between the two scenarios could be recognized in the train's terminus Hamm.

5 Conclusions

The insufficient on-time-running performance at the beginning of the 2003 timetable in North Rhine-Westphalia was due to rolling stock problems and too short dwell times. The investigations concerning adaptations in several services showed that there is still potential to increase the on time running.

With RailSys' ability to construct a network wide timetable including enclosed conflict detection several alterations could be performed. These were dwell time extensions on several services to reduce delays due to higher passenger flows. Also completely new concepts for services with additional speed limits were investigated and solutions were proposed to DB Regio and DB Netz.

The results were possible alterations within the existing timetable or larger adaptations compliant with the timetable concept. The operational simulation verified sensible modifications in the timetable to reduce delays and to improve the on-time-running performance.

The efficiency in constructing and simulating a network wide conflict free timetable shows that RailSys can be used successfully in short-term planning processes. A quick analysis to find out whether timetable concepts can be turned into a working timetable allows railway operators like DB Regio AG to build up coordinated concepts. The constructed timetable data can be used for the announcement of train paths of a railway network provider like DB Netz AG.

6 Perspective

RailSys is a timetable construction and simulation system that can be used on a regular Windows PC. It offers a lot of possibilities for future improvement in timetable construction and operational simulation.

For railway operators competing in bidding processes for regional services it becomes more and more important that future timetable concepts are verified. This implies especially a conflict free construction and can be extended to evaluating the expected operational stability and robustness with the help of a simulation.

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Interfaces to different software systems allow the use of RailSys data in other processes. The timetable data e.g. can be handed over for the construction of a working timetable. Another interface can provide data for the vehicle allocation tool Dispo developed by IVE [4] or the network evaluation model Nemo [5].

RailSys can be used in ad-hoc planning processes during the operation. It is possible to adopt timetables due to temporarily track blockings or speed limits for engineering works. The connection between RailSys and Dispo [6] allows a quick review on rolling stock demands due to timetable changes.

In general the modelling of large networks has improved RailSys' functions to make the timetable construction and the statistical evaluation for more than 8,000 trains a lot more comfortable. For future investigations an automatic path detector is currently under development to find free train slots for additional trains in large networks [7,8].

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