Timetable simulation by sophisticated conflict resolution between train paths

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Abstract

This paper presents a new method for the simulation of the compilation process of conflict-free timetables. These are created in a similar manner to the train path management process on the basis of calculated exact blocking times and explicit conflict resolution. Nevertheless in the simulation the filling of the timetable with trains as well as the conflict resolution are executed by means of an algorithm. This simulation of timetable compilation allows us to answer classical questions about the capacity assessment of the railway infrastructure, and the validation of the new timetable and operational concepts. The improved results of the new asynchronous simulation procedure are due to a more sophisticated conflict resolution method between train movements, particularly on single track lines and in complex networks. This is achieved through the automatic choice of alternative train routes, section-wise resolution of conflicts, and the adaptive calculation of different conflict resolution alternatives using local objective functions whereby the parameters of these include the priorities of the involved trains, additional waiting times caused, the priorities of the used track sections and the distances to remaining conflicts in time and space.

Keywords: timetable compilation, simulation, train path, conflict resolution.

1 Train path management

A central task of a public railway is the compilation of a timetable which has the goal to inform the customer about the supply of train services and, which is at the same time the basis for the network operation. At this it is necessary to coordinate the planning for the individual trains given the available infrastructure in order to assure a punctual and smooth operation.
Train path management is a central part within the process of the timetable compilation at Deutsche Bahn in Germany. For this, the running times and blocking times of all planned trains are calculated by the System RUT as proposed by Brünger [1] to find failures in the planning. Because blocking times describe the occupation of exclusively usable infrastructure sections as block sections or switches by trains the overlap of blocking times of two different trains indicates a planning fault. This is called a conflict. In figure 1 the time-space-diagrams of two trains and the resulting blocking times resulting from the signalling systems are shown. Please refer to Wendler [2] for a more detailed review on this topic.

![Figure 1: Running times and blocking times of two trains.](image)

All overlaps of blocking times and other conflicts are indicated by RUT and must be solved interactively. Besides the interactive resolution of blocking time conflicts in RUT the asynchronous simulation systems STRESI and NSIM determine key figures for the assessment of railway infrastructure on the basis of blocking times and automatic conflict resolution as shown by Schwanhäußer [3]. These existing asynchronous simulation systems use precalculated blocking times, inflexible strategies for conflict resolution and cannot use the infrastructure and train databases of RUT. Regarding the synchronous simulation approach as used by RailSys [4] for instance some disadvantages arise, especially in modelling train priorities and operation on single lines. This is due to the fact that during the simulation the trains occupy the infrastructure synchronously with the model time.

2 Simulation strategy and conflict resolution in BABSI

In this chapter the concept for a new asynchronous simulation system called BABSI is presented. It is based on the ideas of RUT and extends these for
automatic conflict resolution and further simulation tasks. BABSI is has been developed within a PhD-thesis at Aachen University of Technology (RWTH Aachen), Germany by the present author [5].

2.1 Global simulation strategy

BABSI uses blocking times to model the capacity consumption of train paths. It considers priorities while putting the trains into the timetable. Hence as a first step of the simulation all trains are sorted by their priorities. Then all trains of one priority are completely put into the timetable at once. In a next step conflicts are detected and resolved. If all conflicts are solved the procedure repeats with the trains of the next priority. The timetable creation process is complete if trains of all priorities are inserted and all conflicts have been resolved.

Originally all asynchronous simulation systems sort all trains first and insert them one after another into the timetable on their complete running distance while solving the conflicts of each new train directly. Because this procedure does not work section-wise it may lead - especially on single track lines - to train occupations that needlessly reduce line capacity by alternately starting trains at the opposite ends of the line. The same negative effect appears in any approach that iteratively uses complete train path searches for automatic timetable generation.

If a train has to get an additional waiting time for conflict resolution this should be added at a previous railway station where the train stops already. Because of the central aspect of the extension of the stopping times in conflict resolution the simulation system BABSI uses the passing sections known from the analytical methods of railway operations science for dividing the running distances of the trains.

Figure 2: Passing sections of a train run.
A passing section starts and ends on a passing station or at the end of the considered network. A passing station is a railway station where a train can by passed (or crossed) while stopping. Passing sections are depend on the scheduled train stops as well as further train parameters like the train's length or traction mode.

Figure 2 shows a train run together with its passing sections in a time-space-diagram. The first passing section starts at the beginning of the considered network und ends at the first stop of the train in station A. The next sections ends not before the train stops again and can be passed simultaneously. So the next stop of the train at the station X is not relevant. The last passing section ends at the network border.

The new method of BABSI solves the detected conflicts in a way, that the considered trains will have no more conflicts in the current passing section. In general a more distant conflict will lead to a conflict resolution in a subsequent passing section. Because the conflicts are resolved by this simulation procedure in their temporal sequence under consideration of the passing sections there cannot arise timetables with a too low capacity utilisation.

Through the section-wise conflict resolution it is possible that once realised conflict resolutions might have to be modified at a later point of the simulation process because they are not appropriate any more. For example, this is the case if an alternative train route is used at the end of a passing section that does not allow an additional stopping time in that station for a subsequent conflict not yet detected. In this case the relevant section for the conflict resolution will extended by the prior one. This iterative extension of the relevant section of the conflict resolution guarantees that no deadlock is possible during the simulation process.

However it is thinkable that after some successful conflict resolutions at the beginning of the train route, there is no more infrastructure capacity left for this train on a subsequent part of the network, in which case the train path has to be entirely removed. There might exist other trains that have been changed due to the earlier conflict resolutions with the now removed train. These changes are to be taken back and therefore all conflict resolutions and changes for all trains during the simulation must be documented.

### 2.2 Solving of individual conflicts

After explaining the global simulation strategy the resolution of a single conflict is to be described. It should not be a task for the user of BABSI to explicitly define all possible train paths for a given train. Hence these must be determined during the simulation under consideration of the train parameters and the planned stops. This approach can be validly used because the blocking times for a new train path can only be investigated during the simulation process itself. This requirement can easily be fulfilled by using the methods of RUT for calculating the running and blocking times.

As shown in figure 3 the simulation system BABSI determines for each conflict several alternative resolutions. The alternatives are weighted by a local objective function and the best conflict resolution will be realised. With this approach it is possible to solve the conflicts best without using a fixed conflict
resolution strategy or an explicit control by the user. During the determination of the different conflict resolution alternatives the approaches “changing the route” and “changing the stop time” traditionally separated in existing asynchronous simulations are combined in BABS1. Here it is taken into account that each train depends on a route and that stops cannot be defined independently from it.

As shown in figure 4 different conflict resolution alternatives are determined by calculating the necessary changes of the stopping times for the original as well as for alternative routes in order to make the train conflict free in the current passing section. The determined conflict resolution always refers to one train only.

If it is not possible to solve the train's conflict in the original passing section within an acceptable extension time the current passing section will be extended towards to a previous passing station and the detection of the conflict resolutions starts again on this section. If the passing section cannot be extended anymore and no acceptable conflict resolution is found the conflict resolution alternatives based on additional stops are determined. Only when there is no possibility to acceptably solve the conflict it must be decided which of the involved trains
should not be considered anymore and therefore is to be deleted together with its blocking times. The deletion of a train shows that the planned timetable does not fit to the existing infrastructure. This fault must be corrected so that all planned trains fit into a conflict free timetable.

DetermineConflictResolution(Train)

DeterminePassingSection

CalculateStopTimeExtension

all extensions > limit_1?

Yes

DetermineAlternative RoutesAndStops

CalculateStopTimeExtension

Conflict not resolved and passing section extendable?

Yes

ExtendPassingSection

No

Additional stops valid and all extensions > limit_2?

No

No

Yes

DetermineAdditionalStops

CalculateStopTimeExtension

Conflict resolutions determined

Figure 4: Determination of the conflict resolutions for one train.
2.3 **Evaluation of alternative conflict resolutions**

After the determination of possible conflict resolutions the alternatives to be used in the simulation has to be chosen. Therefore all alternatives must be evaluated and weighted by an objective function. Often mathematical approaches for timetabling use sums of scheduled waiting times or the necessary amount of rolling stock for comparing schedules, but these objective functions do not correctly meet the requirements of train path management. On the other hand a good global objective function for timetable quality was not found despite intensive research for some decades.

The simulation approach of BABSI works with blocking times as the central modelling element and the objective function has only to compare concrete conflict solving alternatives. This has strong analogies with the computer based train path management in RUT and therefore it is much easier to find a appropriate objective function.

There exist some meaningful criteria for a local objective function:

1. The scheduled waiting time which describes the reduction of the attractiveness of the train for the customer.

2. A hierarchy of the used train routes is established in order to reflect that further trains with lower priorities might have to be put in at a later point of the process. Hence routes that use sidings or the main track in the opposite direction are assigned a very low priority.

3. It should be taken into consideration whether the conflict resolution in the current passing section leads to a hard conflict in the next passing section. In this way the search for the local optimum for one conflict resolution can be easily extended for the consideration of neighbouring conflicts.

4. The uses of experience or the results of infrastructure assessments can be used to mark some routes or infrastructure elements as bottlenecks which should be treated in a special way during the timetable creation process.

5. The costs of a conflict resolution in terms of the costs of the train paths or the used energy can be used if this data can be determined.

Depending on the use of automatic conflict resolution different objective function can be composed in BABSI. The user must choose the objective function to be used, which has extremely strong effects on the results. For a classical simulation of timetable creation the first two criteria lead to meaningful results.

3 **The BABSI simulation system**

On the basis of the approach for the automated conflict detection and resolution based on blocking times shown before different applications can be realised. As
shown in figure 5 the BABSI prototype which uses RUT as an under laying system provides four different simulation modes. Under the buttons for the four modes two input fields exist where the user can determine the buffer times (German: “Pufferzeit”) that must be considered during the conflict resolution between the blocking times of the trains.

The first one (“Lösungsvorschläge” – conflict resolution proposals) determines the conflict resolution proposals for a single conflict in order to support the computer based train path management. The user can start the algorithm for a single conflict, he gets some suggestions how to solve the conflict and can decide to use these. In this way the efficiency of the train path management will be enhanced increase.

The second one (“Trassensuche” – train path search) searches a train path for a new train. It puts the train into an existing timetable and solves all arising conflicts. Handling of extra trains as part of the train path management can be accelerated considerably by using this method.

The third one (“Simulation der Fahrplanerstellung” – simulation of timetable compilation) creates new timetables from scratch. Beginning with an empty time-space diagram the trains are sorted according to their hierarchy, are put in and the arising conflicts are solved iteratively. The result is an conflict free timetable and the required scheduled waiting times.

![The BABSI simulation system.](image)

Figure 5: The BABSI simulation system.
The last one ("Simulation der Betriebsabwicklung" – simulation of train operation) demonstrates the stability of the timetable in operation. For this random delays are assigned to the trains. The dependencies between the trains result in the propagation of delays from one train to another if there are only insufficient buffer times in the timetable. The work of the traffic control centres is modelled by using the automated conflict resolution for creating optimal dispatch timetables reflecting the current traffic situation.

Even when the latter two simulation modes are primarily used in capacity assessment the former modes show first concrete steps for the automation of generation of entire timetables. Apart from the automation of the train path management process BABSI can be used in capacity assessment but also in short time planning tasks arising from disruption of operations or the non-availability of infrastructure due to construction works.

4 Conclusion

The paper focuses on a recent enhancement of the asynchronous method to simulate timetable compilation and railway operation. The newly developed simulation strategy and the use of appropriate basic components introduced in the field of timetable compilation lead to a simulation procedure respecting train priorities that can be used for various stages of the railway planning process. The use of existing basic components enables the procedure to employ infrastructure and timetable data from the entire German network that are already available.

The new asynchronous simulation procedure provides improved solutions for classic questions of railway operation science, such as the calculation of infrastructure capacity or the validation of new timetables and operational concepts. It delivers better results than traditional asynchronous methods because conflicts between train movements are resolved in a more sophisticated way, particularly on single track lines and in complex networks. This is achieved through automatic choice of alternative train routes, section-wise resolution of conflicts, and the adaptive calculation of different conflict resolution alternatives where the choice is made with the help of objective functions.

The algorithmic complexity of automatic timetable compilation is extremely high and corresponding mathematical approaches have been analysed by the present author in his thesis [5]. There it is demonstrated that, due to the combinatorial variety of possible train sequences and train path alternatives, mathematical approaches require simplified mathematical modelling structures. However, these simplified modelling structures do not contribute to solve the everyday problems of timetable compilation.

Whereas the new procedure is based on concepts similar to the basic ideas of the existing support tool for timetable compilation – namely the idea of blocking times for block sections and the specific consideration of conflicts between train movements – it enables new applications in this area by introducing improved strategies of conflict resolution. As a result, the efficiency of IT supported timetable compilation can be improved as the new method creates various conflict resolution alternatives, searches the existing timetable for free train paths.
and inserts additional train paths by using remaining infrastructure capacity in an economical manner. The operation simulation procedure embodied in the new technique makes it possible to check the stability of any timetable and thus to provide early quality assurance of timetable planning processes.

References


