Reducing delays by means of computer-aided ‘on-the-spot’ rescheduling

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Abstract

Set out in this paper is a means of automatic traffic regulation incorporating the basic aspects of train-path management. The procedure presented herein generates new, non-conflicting running schedules whenever conflicts become imminent due to the operating situation that is obtained. Adopting an asynchronous approach based on blocking times simultaneously ensures that even very remote conflicts can be identified and, indeed, resolved. The new procedure allows conflict-resolution proposals to be submitted to the traffic controller or else traffic to be regulated on an automated basis.

Keywords: rescheduling, simulation, train scheduling.

1 Introduction

In the course of becoming modern, customer-responsive transport enterprises, railways need to guarantee not only that trains are run safely and to schedule but also that the process is efficient and economical. Controllers play a central part in traffic management, determining the sequence of trains on lines and, in the event of delays, instructing the traffic controller to alter the sequence. At all times they are obliged to bear in mind the punctuality and economics of running.

High-quality train regulating decisions are dependent upon the database for conflict detection being substantially improved, since conflicts can only be resolved well if they are accurately detected. It is essential to this end that the blocking times already made use of in railway operation science and train scheduling are also adopted for traffic regulation. For the first time, these enable conflicts to be accurately detected and the means of resolving them to be determined. As well as tapping rationalisation potential, automating traffic regulation can also cause the productivity, quality and flexibility of traffic management to be improved.
Set out in this paper is a new procedure for regulating traffic flows. By using the data on current operating events it is possible to automatically design non-conflicting train-running schedules and use these to directly control operations.

2 Train scheduling based on blocking times

The principles of safety, punctuality, efficiency and cost-effectiveness are of vital importance for railway operations. They need to be borne in mind from the moment the production process is planned and not just when it is being implemented. Production planning where means of public transport are concerned takes the form of train scheduling.

The timetable is accorded a very high status at the railway. Train operators have to plan their production in advance, since a) the timetable has to be published as an offering to their customers and b) punctuality and smooth traffic flows are crucially dependent upon the accuracy of the timetable compiled. The punctuality aspired to is predicated on a non-conflicting timetable. Any conflicts present in the original timetable will lead to delays in running on a daily basis.

Only with the aid of what is referred to as a blocking-time series has it become possible to detect track-occupation conflicts accurately. HAPPEL proposed the blocking-time series as a basis for train scheduling back in 1959 [3]. To date, however, it has not been deployed due to the high input involved when timetables are compiled manually. It is only with the advent of computer-aided systems that blocking-time series can be calculated for trains. Blocking-time series can be made use of both for conventional multiple-aspect signalling and in refined form for more recent systems [9].

![Diagram of blocking time constituents](image)

**Figure 1:** Constituents of the blocking time.

Signalling and train-protection systems create interdependencies between individual train movements. The “running at block intervals” system practised in
Germany, which is necessary due to high traffic densities and long braking distances, divides a line into block sections. It is then vital that there is only one train in any given block section. The main signals at the beginning of a section are set at “stop” or “go” depending on whether the following block section is occupied or clear. Owing to the long braking distances for trains, main signals have to be preceded at braking-distance spacing by warning or distant signals.

To guarantee a train’s unhindered movement, the next block section in advance must already be clear before the train has reached the applicable distant signal. Otherwise, the train would inevitably have to brake and hence be driven in a jerking, stop-start manner. It is for this reason that the blocking time for a block section (cf. Figure 1:) comprises not only the actual running time of the train within the block and the clearing time taken to leave it but also in addition the approaching time (for movement from distant to main signal). To these are further added the sighting time, i.e. the time taken to determine the aspect of the distant signal, and switching times (route formation and release times). Thus constituted, the blocking time for a block section can now be combined with those for the other block sections to form a blocking time series.

Approaches based on blocking times have been proving their worth in systems for the study of railway operations for years. With the introduction of FAKTUS/RUT (cf. Figure 2:) in Germany, such approaches have also been adopted in train-path management. Not until the advent of software support was...
a “true” running schedule guaranteed; graphic representation of the blocking
time series for all trains allows any conflicts between train movements to be
accurately identified and eliminated from the running schedule.

It is essential for the purposes of processing traffic that the timetable be free
of conflicts. Conflicts in the running schedule lead to conflicts in the
implementation of running that have of necessity to be resolved. Quality
assurance ought to be practised at as early a stage as possible, moreover, ideally
during the actual train scheduling process. Traffic can only be properly regulated
on the basis of a non-conflicting, “true”, high-quality running schedule.

Once blocking time series are successfully made use of in train scheduling,
the goal for future developments in the processing of traffic needs to be to adopt
blocking times as the basis for supporting traffic regulation here, too.

3 Automated regulation of traffic flows (rescheduling)

3.1 Principles underpinning traffic regulation

If all trains were to run to time and there were no disruptions to the operating
process, the non-conflicting timetable compiled beforehand could be adhered to
in practice without restriction. The irregularities to which train running is subject
give rise to deviations from the timetable, thus impairing the quality of running,
jeopardising the quality of service purchased by train operating companies and
reducing cost-effectiveness.

By rescheduling services, the traffic controller attempts to keep the negative
impact on other trains of a train running late as low as possible and to prevent
knock-on conflicts arising or at least minimise them. Rescheduling decisions are
necessary to enable the nominal status to be returned to as quickly as possible.
The daily working of trains may be founded upon a timetable that has been
compiled and was originally non-conflicting, but it is nevertheless subject to
influences that can arise either in isolated form as original delays without any
input from other trains or else as knock-on delays caused by other trains [1].
Original delays are brought about by external influences such as defective
signals, broken rails, large influxes of passengers or motive power-unit failure.
Knock-on delays arise as a result of trains impeding one another.

Traffic regulation is an optimisation task in the same way that train
scheduling is. It involves optimising a running schedule to prescribed criteria. In
both cases, however, effecting the optimisation required is such a complex task
that it is unachievable even for comparatively small-scale networks and it is
accordingly necessary to adopt an heuristic approach. The complexity of
automated train scheduling is addressed by Gröger in [2], who also sets out an
heuristic method of performing it. One very effective heuristic traffic-processing
method is asynchronous regulation (ASDIS), which is adumbrated below. A
detailed exposition is to be found in [6].

3.2 Requirements for automated traffic regulation

The principal task of traffic regulation involves identifying and resolving conflict
scenarios in the running process, i.e. in the event of the timetable not being kept to making decisions conducive to the swiftest possible return to the initial running schedule. This has to occur on the basis of events that have happened or are expected inclusive of all attendant impacting factors and influencing variables. To this end, the controller’s office is required to produce a fresh, non-conflicting running schedule that takes account of actual circumstances.

The traffic controller is required to make decisions whenever it becomes clear from the running advice given that a train is deviating significantly from its nominal time-path and conflicts are being brought about. Automated conflict detection and resolution are required to this end as a means of support for the controller, since, once the initial conflict has been resolved, knock-on conflicts arising from the solution found generally remain. Such knock-on conflicts must likewise be identified and resolved. However, owing to the likelihood of further chance factors impacting upon the course of running, it is only possible to regulate traffic with an adequate degree of reliability within a limited operations planning horizon. It is necessary when resolving conflicts to pay suitable heed to the priorities of trains, though there is room for manoeuvre here of course. A train running late may, for instance, be accorded a higher priority to allow it to make good its delay more quickly or, if the delay is too great, may be accorded a lower priority.

3.3 Concept underlying the new approach

The intention in this section is to set out the concept underlying the new approach to regulating/rescheduling trains. What is fundamentally new is the adoption and adaptation of methods from train-path management for the actual working of traffic. The new approach consists of an exact running-time computation that also provides the determination of the blocking times for conflict detection.

Traffic is worked on the basis of a timetable drawn up by train-path managers. Assisted by FAKTUS/RUT software, this is now of a high quality, especially as regards freedom from conflict. As long as no disruptions or instances of out-of-course running occur, this timetable can be made use of for operational purposes. Should any irregularities arise in the course of operations, a new non-conflicting running schedule is produced without any interruption to the operating process.

Figure 3: sets out the process involved in the form of a flowchart [8]. In the first stage use is made of the non-conflicting timetable compiled for pathing management purposes as a basis for the running of trains. This nominal timetable constitutes the first train-regulating schedule and is constantly compared with the actual running schedule necessitated by the current operating situation. Use is made of the running advice received to this end, since it is this advice that enables variance comparisons (between the planned and the actual train movement) to be conducted. Where variance extending beyond a prescribed amount is revealed by such a comparison, a new train-regulating schedule is designed. This new, likewise non-conflicting train-regulating schedule supersedes the previous one and effectively becomes the new nominal timetable.
The process then continues with a new comparisons considering the newly created schedule.

![Diagram of procedure suggested by Schwanhäußer [8].](image)

**Figure 3:** Procedure suggested by Schwanhäußer [8].

### 3.4 Asynchronous train path assignment for automated regulation

Simulation algorithms are divided into synchronous and asynchronous processes according to the way they work. (Time-)synchronous algorithms are used in the familiar SIMU/RailSys [4] or OpenTrack tools [5], for instance, asynchronous algorithms in tools such as STRESI and NSIM [7]. A comparison of synchronous and asynchronous train path assignment algorithms reveals that asynchronous algorithms are more suitable as a means of pre-empting conflicts arising on a network over which very diverse types of trains are operated.

At the same time, however, the asynchronous train path assignment algorithms developed so far need expanding and refining. The mode of procedure in STRESI involves calculating the running times and blocking-time series for trains on some routes in advance of the actual simulation. The trains are then classified in order of priority. Decisive for the order in which trains of the same level of priority are inserted in the schedule is the time of departure from the beginning of their route. A new train is then completely inserted into the running schedule from the beginning to the end of its route. No higher-
ranking train is subsequently handled or displaced to resolve any conflict surrounding this train.

The train path assignment algorithm in STRESI, however, is only designed for the simulation of two-track lines and would not produce practicable results if applied to single-track lines. In the light of this, the asynchronous approach for the NSIM procedure, with which sections of networks can be simulated, has been refined. Trains are no longer completely inserted but only for portions of a route. The other STRESI disadvantages nevertheless remain largely in place.

The train path assignment algorithm familiar from existing asynchronous procedures has been modified so as to negate such disadvantages. Trains are inserted into the running schedule in accordance with their ranking as hitherto, i.e. commencing with trains highest in the hierarchy, then those next highest and so on until the lowest-ranking trains are reached. In a departure from procedures adopted hitherto, instead of inserting one train and then resolving its conflicts, all trains of a given priority ranking are always inserted together without initially resolving any conflicts that ensue.

The upshot is a running schedule containing conflicts between trains of the given priority ranking as well as between such trains and higher-ranking trains inserted earlier. Any conflicts arising are now resolved in chronological sequence. Knock-on conflicts resulting from resolution of a primary conflict are addressed, together with any other conflicts still remaining, in chronological sequence. Once the last conflict to arise has been resolved, a new, non-conflicting running schedule is yielded that covers the level of priority last inserted together with all higher levels in the hierarchy. The procedure is then repeated for the next rank down.

Custom-developed for ASDIS, this new asynchronous method of train path assignment does not require trains of a given priority ranking to be inserted in any particular order. It is thus universally applicable for sections of networks.

3.5 Algorithm for automatic conflict resolution

An automatic conflict-resolution algorithm has the same means of resolving conflicts in the traffic regulation process as are available to the infrastructure manager in manual or computer-aided train scheduling, specifically:

- use of alternative routes
- extension of a scheduled stop
- relocation of passing stops
- additional stops for operational requirements
- extension of running time
- cancellation of train over complete route or part thereof

As a rule, however, any one of the above measures is insufficient on its own and it is necessary, instead, to select a permutation of several options to specified criteria. A local optimisation strategy is adopted to this end, with the additional running time required for the various options generally being applied.
The algorithm initially defines all route options. This involves it conducting searches for all potential routes at a given rail establishment as well as for alternative sequences of rail network. For every route option found a running-time and occupation-time calculation is carried out. It may additionally be necessary to extend the length of a stop on a given alternative route, hence generally making for a longer carriage time. The local optimisation strategy now selects the most favourable route option, which is then put to effect in the train-regulating schedule. All conflicts that have arisen are successively resolved in this way.

In the course of resolving conflicts, it also checked whether a better solution can be found by practising what is known as partial precedence. Under this option, a higher-ranking train may likewise be required to stop for longer than scheduled or else to run in stop-start mode as part of the conflict-resolution process. In the case of disruptions that arise at very short notice, furthermore, it may be necessary to forsake the asynchronous approach and proceed synchronously for a short while.

The rescheduling measures adopted to resolve conflicts are displayed in a window once ASDIS has found a solution to the conflict. The user can additionally infer the solution found for a conflict from the time-paths and blocking-time series (as in Figure 2:). A horizontal red line indicates the current time; the area above this red line represents the past, the area below the future. The user can define the screen window shown and hence the relationship between the past and future areas.

The ASDIS asynchronous traffic-regulation system draws on already familiar asynchronous algorithms yet negates their familiar drawbacks through a wide range of upgrades. The train path assignment algorithm for networks has, for instance, been enhanced, while the conflict-resolution algorithm has been supplemented by a local optimisation strategy that also facilitates the practice of partial precedence. Under certain circumstances, moreover, ASDIS can have recourse to synchronous elements, especially to manage short time conflicts on lines, where the sequence of trains cannot be changed.

### 3.6 Potential applications

The ASDIS method of asynchronous traffic regulation is designed to identify and resolve conflicts on larger sub-networks. This allows use to be made of ASDIS at traffic control centres.

The algorithms developed can produce individual conflict-resolution proposals or else a completely new train-regulating schedule at traffic control centres. In an initial phase, ASDIS can, for instance, help the train controller make decisions. ASDIS would automatically detect any conflicts and, for example, propose several means of resolving them to the traffic controller. The latter is then in a position to either directly implement the proposal or else to interactively design solutions of their own, which are in turn implemented by the system. The scope for intervention the traffic controller enjoys relates to altering the priorities of trains. They can directly influence the conflict resolution process by defining the hierarchy accordingly.
In a subsequent phase, ASDIS would in many standard scenarios then be able to make decisions internally. ASDIS would automatically compile a new non-conflicting running schedule as soon as the governing parameters changed. This would constitute a step towards automated traffic processing, with controllers henceforth merely exercising a supervisory role and only intervening in the system in cases where they have more extensive information than ASDIS does.

4 Concluding summary and outlook

The input to which this paper relates involved developing a new means of supporting the rescheduling of train running. Adoption of methods from computer-aided train-path management has, coupled with an asynchronous approach, given rise to a new train-regulating procedure known as ASDIS, which can be employed in traffic control centres run by infrastructure managers.

It is possible with the aid of ASDIS to compile non-conflicting traffic-regulation schedules that take account of actual operating circumstances. Whenever the current running schedule is deviated from and conflicts arise as a result, a new schedule is produced. On the basis of an exact running-time computation that also provides scope for recovery allowances being reduced in the event of delays, it is possible to produce an accurate forecast of the further course of running of the relevant trains. The asynchronous approach allows conflicts to be detected and resolved that are set to arise far into the future. This is conducive to wide-area traffic regulation.

Employing ASDIS at traffic control centre allows an end-to-end line from planning to operation to be established. Computer-aided train scheduling with the FAKTUS/RUT system has been a standard feature of train-path management for years now. Analytical methods and simulation tools with the aid of performance and scheduling stability studies can be carried out are both available for studies in railway operation science. At the end of the chain is ASDIS, which facilitates computer-aided or even automated traffic management. Owing to different historic data patterns, such compatibility of tools from planning to operation, desirable though it is as a means of enhancing the quality of traffic management, has yet to be attained.

ASDIS takes routine tasks off controllers’ hands. Introducing ASDIS allows a greater degree of automation to be achieved and is hence conducive to improving the productivity, quality and flexibility of traffic management.

References


