Design of regular interval timetables for strategic and tactical railway planning

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Abstract

The role of regular interval timetable planning for railways in general and Railned in particular is explained. The system DONS (Designer Of Network Schedules) is developed to generate these timetables automatically. A powerful user interface enables the planner to specify the timetabling problem at an abstraction level, which is adapted to the planners needs rather than the solver modules needs. A global model of the infrastructure serves as a framework for the definition of defaults for headways, cross-over conflicts, travel times, track usage etc. Train services and market demands can then be easily manipulated, such that various scenarios can be tested quickly. The DONS system was successfully used to advise the government on railway infrastructure investments for the year 1998-2005.

1 Introduction

Timetables form the backbone of the railway operation. Depending on the density and distribution of the population and the economy, the full Passenger Timetable will either be designed train-by-train or be based on a regular interval timetable. The first mode generally applies to long distance traffic in sparsely populated countries (e.g. France, Spain), regular interval timetables are frequently used in densely populated areas, like Holland, Belgium or Switzerland.

The regular interval timetable has been used in Holland for over 50 years. Since the seventies, the concept of regularity on separate lines, has been supplemented with the realization of regular connections between lines. In this way, regular services with reasonable travel times can be provided between any pair of stations.
Phases of the planning process
The expansion of the regular interval timetable to a full timetable is performed in the phase of the operational planning, 0-1 years ahead of the start of the timetable year. The basic ideas of the regular interval timetable serve as a reference for changes which are made in the full timetable.

At the tactical planning level, 1 to 5 years ahead of the timetable year, several versions of the regular interval timetable are developed, based on somewhat differing assumptions of the market demands and with different levels of service to the passengers. In this phase, as during the operational planning, the railway infrastructure is part of the invariable input data. At the end of the tactical planning phase, one of the regular interval timetables is selected to be extended into a full timetable; supposedly, it's the timetable that will create both commercially and operationally the soundest full timetable.

Strategic planning is performed 5 to 15 years ahead of the applicable timetable year. This timespan corresponds with the lead time of infrastructure projects. During this planning phase, a balance is sought between the public transport policy of the government and possible infrastructure investments. The goal is to define a railway infrastructure, that is best able to cope with the scenario that reflects the governments view of the future. Developing regular interval timetables for several variants of this scenario is done to prove the viability of a certain infrastructure proposal.

Railned and timetable planning
The planning of timetables for all purposes used to be the sole responsibility of NS, Dutch Railways. Due to the separation of the ownership and management of railway infrastructure from the actual railway operations, as regulated by the EC directive 91/440, the organization Railned was established in 1994. On behalf of the Dutch government, Railned has the responsibility for the planning and the management of the railway infrastructure.

The Railned Capacity Planning department is responsible for strategic infrastructure planning. It has to advise the government which long-term infrastructure developments are necessary to be able to execute the governments transport policy, as described above.

NS-Reizigers (NS Passenger Services) and NS-Cargo are presently the only operators on the network. They develop timetables at the tactical and operational level. The Railned Capacity Allocation department sets priority rules between the railway operators and the maintenance department, integrates timetables and checks the resulting timetable for stability and robustness.

Development of regular interval timetables
In all railway companies the development of timetables involves a lot of manual labour, even if the administration of the result is supported by computer systems. NS also has such a system for the administration of the regular interval timetable (den Brok & Vissers [1]). Some railway companies are developing intelligent support systems for the scheduling of rolling stock and personnel; the design of timetables is still seen as a craft rather than as a science.

For the Dutch network the lead time for the design of a regular interval
timetable can be up to two or three months. Since there is more and more demand for alternative timetables, either to support a more solid proof for infrastructure investments, or as a management tool to respond to the market in a cost-effective way, a much shorter lead time, in the order of days rather than months, is essential. Therefore, in 1992 a project was initiated to develop an automatic regular interval timetable generator (van den Berg and Odijk [2]). This paper will describe the progress that has been made in the development of this system.

2 Description of the problem

The system DONS (Designer Of Network Schedules) is a Decision Support System for the planning of regular interval timetables. This section describes the way the timetabling problem is modelled.

Defaults play a very important role in the DONS system. Most data needed to describe a timetabling problem, do not vary from one alternative to the next. Rather than describing all these data again and again for each individual train, defaults for headway times, for track usage, for travel times etc. etc. can be defined once, and need only be redefined if an individual train has different characteristics.

Figure 1. Infrastructure map; full window and zoom window.

Global and local timetable planning

A timetable can be taken into operation if no conflicts occur between trains at the most detailed level of the infrastructure; at railways with limited station capacity compared to the train frequencies, such as in Holland, these limitations play a very restrictive role in timetable design. However, solving both the global timetable (the network schedule) and the detailed train movements within stations at the same time, is not feasible from a computational point of view.
A two-level hierarchical approach is introduced. DONS is used at the upper level of this hierarchy. This level involves global representation of the railway infrastructure and reflects the limitations of most infrastructure elements (flying or level junctions, stations with simple lay-outs, movable bridges). The planning of track use in complex station lay-outs is done in a separate step, which is described by Zwaneveld et al. in this volume.

Modelling global infrastructure

The infrastructure is modelled in terms of "timetable points" and connections between them.

The set of timetable points consists of the aggregation over stations, junctions, (movable) bridges; in general, those points which are relevant in timetables. The actual track lay-out of timetabling points is not modelled. In the infrastructure model of the Netherlands, 500 timetable points are defined.

Each connection between timetable points is characterized by its length and by the number of tracks; also, the attachment point of the connection in the timetable point respective to other connections is defined.

Train types

Train types will be assigned to each train in the model. In the Netherlands, the train types Intercity, Interregio, Regio and Freight are used.

For each train type, the user defines at which types of stations it normally stops. Thus, for Intercity trains, he specifies that they stop at Intercity stations only. When defining an Intercity train, the system will automatically add stops at the appropriate stations. The user can alter this stopping pattern for individual trains if necessary.

For each train type, a minimum and maximum stopping time is defined. These can be adjusted for specific combinations of train types and stations (e.g., the IC-trains usually stop 1-4 minutes, but in Amsterdam 3-6 minutes).

Figure 2. Track use defaults
The choice of tracks between stations is usually determined by the train type. A general default specifies left or right hand driving. In case of single or double track this will be sufficient. At quadruple track the user can either specify which train types normally use which track, or he can divide the track use by an onward destination of the trains - see figure 2.

Travel times between timetable points can be defined separately for each track and for each train type, in each direction. In the near future, a travel time calculation module will be able to supply default values.

**Signalling and cross-over conflicts**

For each pair of trains, leaving or entering a timetable point via the same track, headway times apply. Three general defaults are defined. The first default is for two trains leaving, the second is for two trains entering, and the third is the headway for an entering and a leaving train via the same track.

These three default headway times can be adjusted for train types. For each of the three defaults and for each combination of two train types (for instance, the headway time leaving the station, where the first train is an freight train, and the second an Intercity), four new defaults can be specified which are dependent on the "action" of the train in the station (for instance, first train passes through the station, the second leaves after a stop). If these more detailed general defaults are not sufficient, they can be set for each track separately.

The track lay-out in timetable points is not known. However, if the user wants, the system can deduce which train movements will probably cause conflicts. For instance, figure 3 represents the connections of JunctionA to its neighbouring stations. Assuming right hand traffic, the system deduces that trains from StationB to StationC will conflict with trains from StationD to StationB; it will generate the constraints to keep these movements apart by the default clearance time. However, if the user wants, he can switch of conflict generation altogether for this junction, or he can switch on or off the conflict generation for any combination of movements within the junction.

![Figure 3. Infrastructure model of a junction.](image-url)
If the timetable point where a conflicting movement should be detected is not a junction but a station, and if the train(s) stop(s) there, it is relevant to know whether the conflict will occur before arrival, after departure or always at a specific side of the station. All this can be specified for each station. In this way, without defining the actual lay-out of the station, many of the conflicts which can occur can be resolved.

Movable bridges play an important role in the Dutch timetable. For each bridge is specified how often it should be opened each hour for the shipping traffic, and for how long; e.g., twice per hour, 5 minutes each. Since trains have priority over ships, these periods can be fixed in the timetable. In the model, during the time the bridge is opened, no train can enter this timetable point from either side, on all tracks.

**Train services**

The previous paragraphs described all more or less fixed input data. The actual problem definition starts with the definition of trains or train series.

Planners determine with assistance of the computer program PROLOP (developed by IVV-Braunschweig) along which routes and at which frequency trains should run. This program calculates from an origin-destination matrix a optimal set of lines and connections. Operational constraints and other considerations will dictate a different set of lines; PROLOP then can recalculate in which way passengers will redistribute themselves over the network. In an iterative process, which also involves the regular interval timetable design, the planner designs a coherent set of train services.

A train series is an aggregate of individual trains. The minimum is one train (per hour) from station A to station B, and its counterpart from B to A. Many trains run at a frequency of 2, 3 or 4 times per hour.

The user specifies a train series by specifying its number, the train type and the origin and destination station. The system calculates the shortest connection between start and end station, and shows the result on the infrastructure map. If necessary, the user can add one or more "via" stations.

The frequency of the train series is also specified, plus an interval for the allowable deviation from the "ideal" interval time (for instance, for a series running twice per hour, the second train may leave 28 to 32 minutes after the first train, instead of the ideal 30 minutes).

Conflicts at stations and junctions are generated according to the infrastructure and the train-type defaults. However, these conflicts can again be switched on or off at the series level, and cross-over clearance times corrected.

**Market demands**

Defaults for station times were already specified at the train type level, possibly adjusted for specific stations. If necessary, they can be redefined again for specific train series.

The average speed of train series can be controlled by specifying the minimum and maximum speed between any two intermediate stations. In this way the station times can be limited to an overall total, which is especially
useful for freight trains, which are usually defined with a large number of non-
compulsory long stops, in order to allow faster passenger trains pass.

Fixed or absolute times (or timeslots) can be specified. This is used for
international trains, of which the arrival times at the border stations cannot be
changed.

The precision of the frequency of a train series was already mentioned. If
two series, both with a frequency twice per hour, have a joint section from B to
C, the planner will most likely want to run approx. 15 minutes apart. The
definition of a "super-series" provides this functionality.

Last but not least, all train series are strongly interrelated, by arrival-departu-
re connections. For instance, in station A, the departure of train 2 should be
between 3 and 8 minutes after the arrival of train 1. The system can handle the
connection of a train series with a frequency of 1, to a train series with a
frequency of 2 or more: it will generate constraints that enable the solver to
make a connection to one of the trains in the series.

In all, the Dutch timetable model specifies approximately 120 passenger
train series, running once or twice per hour, and 15 paths for freight trains.
Passenger trains connect on average to 3 other trains.

3 Generation of the timetable

Constraint generation
The problem is defined by the user in a high level format. Conflicting train
movements, headway times, travel times, the order of stations, the use of tracks
etc. are defined independent of the definition of trains (exceptions excluded).
Trains are not defined individually, but in the form of train series.

The constraint generation module generates two types of files. One file
relates for all individual trains (as derived from the train series) the departure
time at any point along its route, to the departure time at the previous point; the
difference depends on the travel time (which is constant) and the stopping time
(which may be within a certain interval), in total there are about 2500 lines.
Another file relates the departure times of different individual trains at the same
or at different locations; these constraints will guarantee that headways are
kept, that conflicting movements are avoided, and that connections in stations
are held. Each single specification of the user (e.g., a headway time at a certain
track, or a connection between train series) will thus generate a large number of
individual constraints, depending on the number of trains involved and the
complexity of the input by the user.

During the constraint generation, the completeness of the specification is
checked. For instance, for all train series travel times should be available, either
individually defined or by default.

The set of files, containing approximately 10.000 infrastructure related
constraints and 2000 market constraints, is then ready for the solver.

The network solver
As described by van den Berg and Odijk [2], CWI (Center of Mathematics and
Informatics, Amsterdam) developed the solver CADANS.
To search for a timetable, CADANS constructs a search tree, the nodes of which correspond to partial timetables. In each node the timetable constraints are propagated and the remaining freedom, if any, is used to branch. See Voorhoeve [3] and Schrijver & Steenbeek [4]. Since its original development in 1994, the algorithms of the module have been tuned and adapted to cope with the increasing problem size and complexity.

First CADANS finds out if the set of constraints is consistent, i.e. it finds out if a solution for the problem is possible. If not, which is quite often the case, it will select, from the set of constraints that was offered to CADANS, a minimal set of constraints which form an inconsistent set among themselves. Modifying any of the constraints in this set (or rather, the infrastructure limitations, series definitions or market demands that caused these constraints) is necessary and may result in a feasible overall solution.

Depending on the users choice, CADANS can release constraints that were generated from market demands (connections), if it cannot find a solution otherwise. This mechanism will be refined in the near future; presently CADANS releases individual constraints. However, the release of constraints should be in accordance with the way they were generated: if a specification of a connection between two train series generates a group of eight individual constraints, the meaning in real life of the release of only one of these constraints is at best unsure.

After finding a solution, this can be optimized for minimum station and connection times, and optimal interval times for train series. CADANS will do so by using the weights or priority levels that were entered by the user.

Evaluation of the output of the network solver
The network solver can generate the following two forms of output:
- inconsistent subsets of constraints;
- solution to the problem in the form of a feasible timetable.

In the near future, the inconsistent sets of constraints will be translated back to the original user input, such as infrastructure limitations, series definitions or market demands. The individual constraints that cause the insolvability mean little to the users.

The timetable is transformed into a general format and stored in the database. The system can present the timetable as a diagram. Further diagnostics, such as the calculation of the use of junctions, the stability of the timetable etc. will be added in the future.

Improvements in the solver process
One of the major drawbacks of the present DONS system, is the unpredictability of the characteristics of the generated solution. In the manual solution process the planner will start with a subset of the network that is known to be the most limitative, and construct the rest of the timetable from that point on. The planner will tend to incorporate later changes to his original problem definition by changing as little as possible to his original solution. Of course, this way of working is practical, but will lead to sub-optimal solutions in the end. When this is perceived, the planner will start all over again.
The present form of DONS may need some hours to find an initial feasible solution. Unfortunately DONS always generates a new initial solution from scratch. If only a minor modification in the problem specification is made at an insensitive point, the system requires the same time to find a solution; in the worst case, this solution might be very different from the original solution.

Several improvements will be added in the system in 1996. By using the planners knowledge of the most difficult sections of the network, CADANS will be able to check first if a solution in these difficult sections is feasible at all; this resembles the manual way of constructing a timetable.

Another improvement will be the possibility to "fix" certain parts of the timetable (either geographically or by train type) once a solution is found. The timetable can be fixed by absolute times or timeslots, or just by the order of trains on tracks. If the planner makes small changes to the problem specification, he can choose whether he wants the solution to be generated from scratch or take the previous solutions as a starting point. A similar improvement will enable to select only a part of the problem specification (again, geographically or by train type) to be solved by CADANS; in this way he can build or break down the solution obtained step by step.

The handling of weights and priorities will be improved by classifying the market demands, and attaching weights and priorities to these classes rather than to individual demands only. Presently the exact mechanism of the optimization process is hardly understood by the planners, which is caused by the practical impossibility of handling the weights.

Other new functionalities
An important addition in functionality is the module STATIONS (see Zwaneveld et al., in this volume), which will enable the planner to generate routings through complex stations. Apart from generating an exact timetable, CADANS can also specify which deviations from the original arrival and departure times for trains at a pre-specified stations are possible. Once STATIONS is fully integrated in the DONS system, this module will be able to use this flexibility if necessary, and generate a routing for all trains and an adjusted timetable for the station studied. In the next step the network timetable should be recalculated by CADANS, the existence of an updated feasible network timetable is guaranteed. The allowed deviations for another station can now be determined.

The study of Odijk et al. (in this volume) focuses on the automatic generation of a large amount of different timetables for smaller parts of the network, and taking a representative selection out of this number to evaluate infrastructure designs. The idea is, that for strategic long-term studies, the development of full network timetables should no longer be necessary; even though through the study of more scenarios the sensitivity of a proposed infrastructure development to specific timetable solutions can be decreased, it is felt that in the end solutions which address the problem at a more local scale, have more general validity. The advent of safety mechanisms which can manage train movements much more precisely than at present, would advocate this idea.
4 Results

The development of CADANS in 1994 has shown that the automatic generation of network schedules with the size and complexity of the Dutch railway service is feasible. However, only after encapsulating this module in the DONS system, which provides the possibility of entering data at a higher level of abstraction, and added functionalities such as project administration, CADANS became an useful and accepted tool for the Railned Planning and NSR departments.

Although still in development, the DONS system has played an important role in the 1995 Railned study for infrastructure investments in the period 1996-2000 (TTP, [5]). For this study, three transport scenarios for future railway transport were developed. One scenario, the "mainport" scenario, sketched the development of the rail network for an optimal international connections of the port of Rotterdam, the airport of Schiphol and the major cities of Holland. A second scenario focused on a maximum decrease in traffic congestion in the economical heart of the Netherlands, the Amsterdam - The Hague - Rotterdam triangle. The last scenario suggested rail infrastructure improvements in the other regions, to improve their economical situation.

The necessary infrastructure investments for each of these scenarios were studied by generating timetables with the DONS system. The various alternatives were presented to the government, which will now decide how to proceed with infrastructure investments in the next 8 years.

References


