

Improving the Dutch railway services by network-wide timetable simulation

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Abstract

The DONS system, Designer Of Network Schedules, supports the development of timetables by generating regular interval timetables for the Dutch railway network; it is used to plan improved or new train services and to locate bottlenecks in the railway infrastructure.

A new simulation module enables the planners to study the network-wide dynamic properties of DONS timetables. The direct link between DONS and this simulation module, enhanced by the re-use of previously defined DONS concepts and the automatic generation of simulation models from existing data, facilitates an integrated approach towards infrastructure and railway services development, focused on quality improvement.

1 Introduction

Railned advises the Dutch government on railway infrastructure development. Starting from one or more economic scenarios for the future, Railned develops a number of alternative railway service plans; the feasibility of these service plans is tested on the current infrastructure, to locate bottlenecks in the infrastructure. This is done by generating timetables: if timetables can only be generated by releasing some of the constraints or by reducing the number of trains, this points to limitations in the infrastructure which have to be solved.

Railned also allocates network capacity to train operating companies. Part of this task is to integrate proposed timetables or requests for train paths into a single - and feasible - timetable.

For both Railned departments, Capacity Planning and Capacity Allocation, the next question is: will the timetable (or the timetable-infrastructure combination) warrant a sufficient quality standard? The feasibility test should ensure that the timetable is free of conflicts and incorporates buffer times according to the rules-of-thumb that have been accumulated in railway business over the years. In a simple system, this might be enough to establish an acceptable quality level of the railway operation. However, in a heavily loaded, and, even more important, heavily interconnected system as we find in the Netherlands, small disturbances in the operation of the trains may cause network-wide effects on the punctuality. Therefore, Railned decided to construct a tool, which enables us to study the propagation of these disturbances through the network. Simulation is the obvious method for the study of the effect of dynamic disturbances in a complex network.

This paper starts with an overview of the concepts and the functionality's of the Designer of Network Schedules (DONS) system. Concepts and output of DONS are input for the robustness study and its concepts will be re-used in the new tool.

2 Timetable planning

In the Netherlands, defining a timetable, is a process with several steps:

1. design of train services, i.e. line system, frequencies, connections etc.;
2. construction of a network timetable for a "standard hour", also called a regular interval timetable;

3. check and optimisation of track and platform usage in the larger stations for the regular interval timetable;
4. expansion of the regular interval timetable to a full 24-hour timetable.

In the Netherlands the full timetable is firmly based on the regular interval timetable; even almost all peak hour services are fitted within the “regular interval” grid. Thus, for the Railed Capacity Planning department, advice to the government on infrastructure projects is founded on studies of regular interval timetables. For the Capacity Allocation department, the integration of separate timetables of the train operating companies starts by checking the feasibility of integrating them on a regular interval basis.

3 Overview of timetable generator concepts

The DONS system supports the generation of network-wide regular interval timetables and the planning of platform use in large stations (see also Hooghiemstra¹ and Zwaneveld et al.²).

3.1 Network timetable-planning concepts

Infrastructure for the network timetable is defined in global terms, as a set of “Timetable Points” and the connections between those points.

All stations, junctions and other points relevant to the timetable will be elements of the set of Timetable Points; in Holland, we have about 500. In a Timetable Point, a train may start, end, halt or run through; all interactions between trains, such as connections or possible conflicts are also located within the Timetable Point.

Timetable Points are linked by one or more “Connecting Tracks”. For each Connecting Track the length, energy supply and speed restrictions are specified.

By using a graphical interface the planner can quickly change the infrastructure layout by adding, removing, quadrupling lines etc.

The planner defines train services by specifying train type, type of rolling stock, number of trains per hour and the origin and destination station. The system calculates the routing between stations, it derives stopping behaviour from the match between type of train and type of station, and it calculates travel times from the type of rolling stock and the route. The planner can override any of these calculated values for a specific train service or at a higher default level. The planner also

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specifies connections between train services and other types of relations between services. The problem definition is now complete.

Next, the system generates a set of constraints, which represents the problem mathematically. Constraints come from many sources. Travel times (constant) and halting times (may be variable), plus possibly a maximum travel time between the end stations, constrain the timetable of an individual train. Headway times limit how quickly trains can follow each other. The system also has rules for constraint generation to avoid conflicting movements in Timetable Points; the planner can fine-tune these rules, so that for all junctions and smaller stations a complete set of conflict constraints can be generated. Other types of constraints manage the connections between train series and the deviation of individual trains within a train series of the ideal interval time (e.g. exactly every 30 minutes).

The solver module evaluates the list of constraints and then starts to search a solution. If specified, it will drop soft clusters of constraints when necessary; the solution, if available, can be optimized according to weights set by the planner.

The output of the solver is presented in the form of a feasible timetable or as an inconsistent subset of the original set of constraints. Various analysis functions facilitate the interpretation of the output.

3.2 Routing trains through complex stations

After the successful generation of a network timetable the planner will want to know if this solution is also feasible for the large stations in the network. At larger stations there are usually many options to route trains and to use platform tracks. At the same time, there are many limitations: buffer time between occupations of track sections should be maximized, some connections should be realized cross-platform, trains in the same direction should start from the same platform etc.

The stations solver module tries to route as many trains as possible, while granting as many planners' requests as possible. The output of the solver is a platform occupation diagram and various statistical data on the usage of platform tracks and other infrastructure elements and a list of trains that could not be routed at all.

If the solution is not satisfactory, the output may be used to add or relax constraints at the network level (to obtain a new network timetable) or to pinpoint bottlenecks in the station infrastructure. By editing the infrastructure (adding or removing platforms, switches etc.) the planner can study which layout will satisfy the demands.

4 The robustness of network-wide timetables

All kinds of disturbances, caused by a widely varying range of sources, influence the punctuality of railway services. These disturbances can be grouped according to the way they are managed in daily practice:

1. by using up buffer times or slack time which is present in the timetable;
2. by re-planning the logistical process (cancelling or re-routing trains, changing rolling stock or personnel rotation etc.).

Typically, disturbances of type 2 are related to major incidents: defective rolling stock, missing train staff, accidents at road crossings etc. They are handled by some type of – planned or unplanned – crisis management and severely disrupt the railway operation.

Type 1 disturbances are caused by all minor incidents that we consider being part of the “normal” railway operation. Examples are delays in departure because of reaction time of staff, slowly boarding passengers, adverse (not too adverse!) weather conditions, driver behaviour etc. These disturbances are small in size (up to maybe 10 or 15 minutes), happen frequently and are stochastic in character.

The robustness of a timetable is directly related to the sensitivity of railway services to disturbances of type 1. In the planning cycle the robustness test would follow the timetable planning. A timetable might be planned with little slack time (which may be present in travel times, halting times, connections, headway or crossover times etc.); in that case even a minor disturbance causes an instability that will not be neutralized within a reasonable time.

Several studies to test the robustness of a timetable are possible:

- propagation of a single initial disturbance through the network;
- the effect of the “normal” stochastically distributed disturbances on network behaviour;
- sensitivity of specific train series or specific locations.

The timetable used may be a – repetitive – regular interval timetable, a constructed or an actual 24-hour timetable. Results of the robustness test may very well lead to adjustments or re-design of the timetable. Therefore, testing the robustness of a timetable using network simulation is seen as an integral part of planners’ work.

5 The simulation model

To study the effects of dynamic disturbances in a complex network, a simulation model was developed. Its conceptual model is based on the DONS network model. This is justified, because the simulation model has to re-plan the timetable in case of disturbances to keep it executable at all times. In this process the same constraints, like headway times and halting times, have to be taken into account as during the generation of the timetable by DONS. Some extra functionality had to be added to the “Timetable Point” and “Connecting Track” concepts to allow for the dynamics of the system.

In a Timetable Point, the planner can introduce small disturbances that cause initial delays. He can apply these disturbances to specific trains, train classes etc. The degree of propagation through the network is a measure for the robustness of the timetable.

Disturbances propagate only when trains interact. In the DONS-system, some of these interactions are modelled, such as connections between trains and conflicting routes. For simulation purposes, some interaction aspects were added to the Timetable Point:

- capacity: the maximum number of trains in a Timetable Point. The capacity can be subdivided in groups of platform tracks, which are allocated to specific trains. If no platform capacity is available for a train, it has to wait on an adjacent Connecting Track;
- conflict-routes: extra conflict-routes can be defined to model the effect of crossing movements of trains within a Timetable Point.

Travelling through the network, trains are separated (on exit and on entrance of each Timetable Point) by the minimum headway time, which is specified in DONS for each Connecting Track. In the simulation, the Connecting Track may be used as a buffer to “store” trains which are unable to enter the next Timetable Point. This storage capacity, which conforms to the number of blocks of the track, was added to the Connecting Track concept.

The described conceptual model applies as long as disturbances are small enough to consider the original timetable as a reference to re-plan. Only when the simulation model has to deal with heavy disturbances, where structural re-planning is necessary, traffic-control rules must be added that will safeguard the quality of the service. Although strictly spoken not part of the robustness study, some functionality to test traffic-control has been added.

6 Implementation of the simulator in ARENA

The construction of the simulation concepts doesn't have to stop on the drawing board, when using a tool that supports the implementation of software components in a so-called template. A template is a collection of user-defined, re-usable modelling building blocks, which are created by programming their functionality, interface, animation and performance indicators. The use of templates has the following advantages (Pater & Teunisse³):

1. reduction of model construction time, due to the re-usability of complex concepts;
2. separation between design and implementation; the user can concentrate on functional rather than technical problems;
3. verification of entire models is easier because of separate verification of the building blocks;
4. experimentation is much easier because both parameters are changed on easy-to-find spots and high-level building blocks are added instead of changing low-level code;
5. construction of models using available templates does not require simulation experts;
6. automatic generation of simulation models from a database is possible.

For the DONS-simulator a template was built in the Arena simulation environment⁴, one of the first simulation environments to incorporate the template technology. The template contains four building blocks. The blocks Timetable Point and Connecting Track model the infrastructure; the Definition-Block defines the simulation-scenario in terms of the timetable to be used, default-values for headway times, crossover times and the output that has to be generated. Finally the Animation-Block can be used to enhance the animation of the results of the model.

The standard animation shows the trains running on the modelled infrastructure. By the colour of a train it is possible to determine the type of train, i.e. cargo or high-speed, and the amount of time it is delayed. An animated Timetable Point has the same colour as the train with the largest amount of delay that is present within the Timetable Point.

The Animation-Block provides the functionality to show output statistics during simulation, measured for certain types of trains, a Timetable Point or Connecting Track. It can also be used to show which actions are being performed within a Timetable Point, i.e. stopping, or waiting for a connection.

7 An architecture for a network-wide simulator

The final goal is to integrate the DONS-simulator with the existing applications and create a tool, which has the functionality that is required to generate a timetable and subsequently determine its robustness. In figure 1 the resulting architecture of this tool is shown.

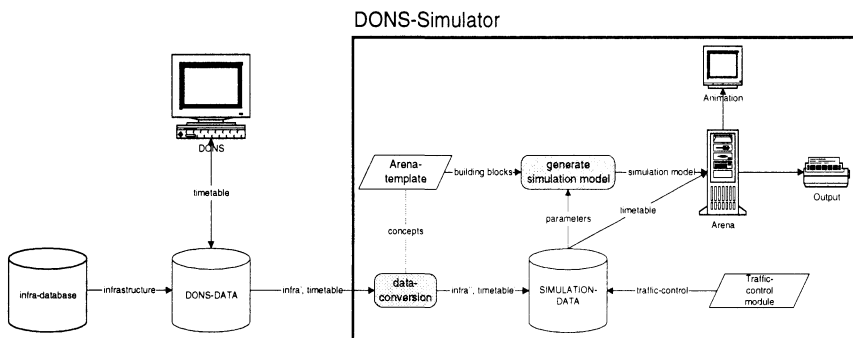


Figure 1: Architecture of DONS and DONS-simulator

The Dons-simulator is linked to the DONS-database, which contains the data about infrastructure and accompanying constraints. Partially this data is again derived from the Dutch Railways corporate database. The timetables that were generated by DONS are also stored in the DONS-database.

The template technology enables us to generate simulation models directly from this database. This saves us the time-consuming job to build the model; verification of the model is implicit.

When the planner wants to test the robustness of a timetable, he selects the timetable and the accompanying infrastructure and constraints from the DONS-database. The system converts these data to a suitable format and stores them in the simulation-database. The planner can also define certain traffic-control rules that have to be operative during the simulation run. These rules are also added to the simulation-database. Now, applying the data-definition of the Arena-template, the simulation model can be generated, including the animation, and the simulation run can be activated.

During the simulation the animation of the model can be examined to understand the results from the simulation. This becomes more difficult as the scope of the simulation model expands. Therefore other applications are developed, to visualise the generated output as

soon as the simulation has ended. In this way a thorough analysis can be carried out retrospectively. Examples of these visualisations are the time-distance and track occupation diagrams.

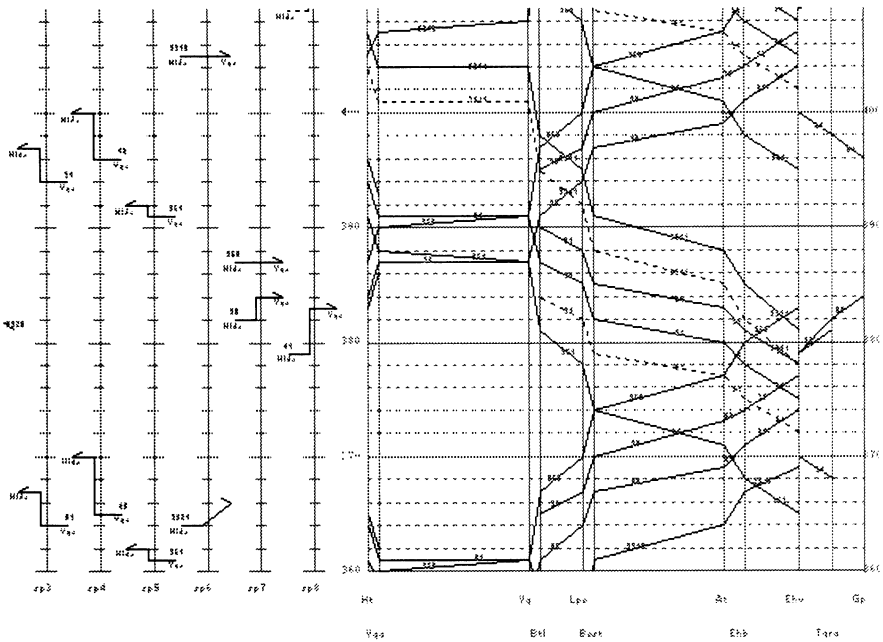


Figure 2: Time-distance and track occupation diagram – plan and realization.

8 Results and conclusions

Already a fully operational prototype of the DONS-simulator has been built, partly integrated with the DONS-system. Reactions of planners, used to working with the DONS-system, are positive. The tool is easy to operate and the level of abstraction conforms well to that of DONS.

During the prototyping phase it became also clear that there is a need for additional ways to interpret the simulation results. New or more precise performance-indicators have to be defined. To inspect the propagation of traffic disruptions in space and in time, more advanced presentation techniques will have to be designed and implemented.

A logical next step in the planning-process is the determination of the robustness of a timetable within a station; this step would be somewhat equivalent to the step from network timetable planning to

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station routing. Building blocks have to be designed to model the infrastructure within a station. The concepts of the Rail-template, as described by Pater and Teunisse³, can be re-used for this purpose.

Although the DONS-simulator is originally meant to test the robustness of timetables, the functionality of the simulator has been extended with traffic-control rules. In this way we can test the effectiveness of control strategies to manage larger disturbances.

Last but not least, a lot of attention will have to be paid to the validation of the model. Comparing the results with real-life data should enable us to tune the model where necessary, and in the end provide a better understanding of the intricacies of the relation between timetable planning and the quality of the railway service.

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