

THE USE OF SIMULATION IN THE PLANNING OF THE DUTCH RAILWAY SERVICES

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ABSTRACT

The design of a quality timetable for the Dutch Railways is a complex task, because of the characteristics of the railway services. The complexity of the network and the heavily interrelated behavior of train operations, often cause small disturbances to lead to heavily disturbed operations. As a result the passenger often experiences less reliability and punctuality of the railway services than desired.

Supporting the planning process with the right tools is therefore a must to guarantee a high quality of the final railway services. The design of a timetable is already fully supported by the Decision Support System DONS (Designer of Network Schedules). To evaluate the robustness of a timetable, Railned decided to construct a simulator as an advanced analysis function for the DONS-system. The DONS-Simulator enables us to study the effect of small disturbances on the punctuality of train operations in the full Dutch network.

To avoid cumbersome and error-prone data entry to construct a simulation model, the simulator is linked to the DONS-database. The template technology of the Arena simulation software, in which the DONS-simulator is built, enables us to generate simulation models directly from this database.

Already a fully operational prototype of the DONS-Simulator has been built, partly integrated with the DONS-system. First reactions of planners, used working with the DONS-system, are positive. The simulator will be further developed and first be used to evaluate the infrastructure investments between 1990 and 2000, in terms of their effect on punctuality.

1 INTRODUCTION

1.1 Railways in the Netherlands

The Dutch railway network is a mere 2750 kilometers long. However, with a population of 15 million, each day close to 1 million passenger trips are made, with an

average length of 42 kilometers. On average, 8 % of all passenger transport is to be attributed to the railways; on some relations in the heavily urbanized "Randstad" area (Amsterdam, Rotterdam etc.) this is up to 40 %. Thus, railway transportation plays an important – and growing – role in de-congesting the road system. The role in freight transportation is marginal; only a few percent of all trains are freight trains. The building of a new freight-only line from the Rotterdam harbor to the Ruhr area will give a major impulse to this sector.

The "planning of Dutch railway services" in the title refers to the strategic planning of infrastructure and the planning of railway timetables.

1.2 Planning of Railway Infrastructure

The revival of the interest in railways as a means to combat roadway and airway congestion has led and is leading to a number of plans for new infrastructure, in the Netherlands as well as in many other countries. New infrastructure plans range from the modification of station layouts, the quadrupling of double-track lines to the construction of new lines. In the Netherlands, the upgrading of the Amsterdam-Utrecht-Arnhem-line for high-speed trains to Germany, is an example of improving existing infrastructure. A new line will be built to accommodate the high-speed trains from Amsterdam to Paris and London; the freight-only "Betuwe-lijn" from the Rotterdam harbor to Germany is another example.

1.3 Timetable Planning

The timetable in the Netherlands has a peculiar characteristic: it is constructed on the basis of a regular - hourly - pattern, which repeats itself from early in the morning to midnight on all lines. Train frequencies at any section range from 1 to 8 per hour for each direction, on double track lines. Since the Netherlands is a small country with a well-developed infrastructure, relations between living areas and economical centers are more diffuse than in larger countries with a more independent regional

development. This means that even in peak hours on many lines trains are heavily loaded in both directions. The high penetration of the railway services and the regularity of the service at all hours has caused off-peak travel for business or leisure purposes to be relatively important.

Thus, connections between train services at large stations are considered to be important, even at high frequency services. A “good” connection means that a passenger can change trains with a maximum delay at the station of 5 minutes. Therefore, a train, which is running 2 minutes late, is already endangering the service that the railways want to offer to the public.

1.4 Reliability and Punctuality

We consider reliability to mean the door-to-door reliability a transportation service can offer to the public. A passenger starts travelling on his doorstep, and the certainty, with which he can plan the arrival time at his final destination, is the “reliability” of his journey. The same holds for the transportation of cargo. In the reliability of these transportation chains the train service plays only a partial role, which we will call punctuality. It is the degree of certainty with which a passenger, given the start of his rail trip at an advertised departure time, will arrive at his rail destination at the advertised arrival time, even if he has to change trains one or more times on the trip. Therefore, punctuality is not only defined by the precision with which individual trains keep to their schedule; management of relations between trains is also an important issue.

1.5 The Railed Organization

Railed has several tasks relating to the management of the railway network, which is owned by the government. Two of these relate to the punctuality issue:

- It advises the government on strategic infrastructure development, and thus is the starting point for the construction of any new infrastructure. The new infrastructure should of course be able to accommodate future train services; the potential punctuality of these services is one of the points to be evaluated. This task is called Capacity Planning;
- It allocates network capacity to train operating companies. Part of this task is to integrate partial timetables or requests for train paths into a single timetable, which should ensure that a certain level of punctuality can be maintained. This task is called Capacity Allocation.

The Railed Department of Innovation supports these functions by developing methodologies to assess punctuality, among others.

This paper starts with a more detailed description of the planning process and the different types of disturbances in the daily operations that may influence the punctuality of

the railway services. Next an integrated Decision Support System is described, that supports the execution of the planning process. This system consists of a timetable generator, to design a timetable, and a simulator to determine the robustness of the generated timetable. Finally a project will be described shortly in which the simulator will be used to evaluate the infrastructure investments between 1990 and 2000, in terms of their effect on punctuality.

2 INFRASTRUCTURE AND TIMETABLE PLANNING

Given the integrated network design of the Dutch passenger timetable, infrastructure planning is strongly related to timetable planning: which infrastructure development will support “best” a certain selection of train service scenarios or timetables?

The process of infrastructure planning involves a number of subsequent steps, with various feedback loops:

1. Estimate the demand for rail transport from national economical scenarios;
2. Design a line system or service structure;
3. Test the feasibility of the line system, given an infrastructure;
4. Evaluate network performance and other parameters;
5. Define an infrastructure project and start again at step 1.

The feasibility (step 3) is tested by constructing a regular interval timetable, which corresponds as closely as possible to the service structure that was defined in step 2.

In the evaluation several parameters are measured. Of course economical benefits and costs are important. A carefully designed timetable, which can also be operated with high precision, may lead to a higher demand for rail travel (step 1 to be re-executed). Timetables, which poorly reflect the proposed service structure because of limitations in infrastructure, will lead to the definition of infrastructure projects (step 5). A description of the process of infrastructure design is to be found in Hooghiemstra et al. (1998).

Essentially timetable design for operational purposes follows the same steps, with the exclusion of step 5: infrastructure is not a variable anymore, only the line system can be adapted.

3 PUNCTUALITY IN RAILWAY SERVICES

To some degree, timetables are constructed to allow for deviations in the real-time operation of the train service. Buffer time or slack time is usually present in the travel time of trains: a few percent is added to the theoretical time, to allow for sub-optimal engine performance, meteorological conditions, driver behavior and late departures. Headway times (minimum time between trains) in planning is usually somewhat more than the technical minimum, which is dependent on the safety system only, to allow for reaction time of the traffic controller and the driver.

In the daily operation of a railway, many different types of disturbances occur, which can be classified by the way they are managed:

- Management by re-establishing the original plan: connections between different trains may be broken, trains may be late, station times may be reduced, but generally the logistical process remains intact. The traffic controller tries to solve the problem by using up the margins that are built into the timetable;
- Management by re-scheduling: trains may be re-routed or cancelled, essentially a new plan is made. The logistical process is severely disrupted. The goal in the end is to re-establish the original plan, this may take several hours (or even days, for rolling stock rotations).

The first type of disturbances is caused by minor incidents, like prolonged station stops because of crowding, staff reaction time etc. The second type is caused by major incidents: accidents on level crossings, engine failures etc.

Management of disturbances of the first type is predictable; there are rules how long trains may wait at stations for connections, in some cases there are also clear rules to change the order of trains in one direction if just one train is late. Management of large disturbances is hardly predictable: these incidents occur infrequently, and even if a prescribed way of management is available, the outcome still depends very much on the exact circumstances and on whoever is responsible for traffic control at that moment.

Obviously, both types of disturbances strongly influence punctuality and thus are of importance to passengers. Frequent travelers perceive these disturbances differently: occasional large service disruptions can often be explained and accepted: day-to-day lateness of trains, with broken connections every few days, cannot be explained and should be avoided. Apparently, a small chance of a large disturbance is more acceptable to the public than a small disturbance happening frequently.

4 SUPPORTING THE PLANNING PROCES

As mentioned before, the planning process involves a number of subsequent steps, each with different characteristics. To be able to design a timetable that meets all demands, one needs an integrated Decision Support System (DSS) that supports the execution of each step of the planning process. This paper concentrates on the support of step 3 and 4 of the planning process: the feasibility test of the line system, and the evaluation of network performance and other parameters.

Step 3 is executed by constructing a timetable, which corresponds as closely as possible to the service structure that was defined in step 2. Step 3 is already fully supported by the Decision Support System DONS (Designer of Network Schedules) (Hooghiemstra, 1996 and Zwaneveld et al., 1996).

DONS is a timetable generator that constructs a timetable in a two-step process:

- In the first step DONS searches for a solution of the network problem: can a timetable be constructed, given the requested service structure? Limitations are defined by the planner as the travel time of trains, the headway times for trains, possible conflicts at junctions etc.
- In the second step, the limited capacity of large stations is taken into account. For each large station DONS tests the feasibility of the network solution: is it possible to route trains conflict-free through the station, and to allocate sufficient platform capacity to each train?

Once a timetable is constructed, the network performance has to be evaluated (step 4). To support this step, one needs to be able to study the network behavior when submitted to frequent but small disturbances, the first type of disturbances as described in the previous section. Railed decided to construct a DONS-Simulator, as an advanced analysis function for the DONS-system. This enables us to study the propagation of these disturbances through the network. The goal is to find out if timetable construction can be refined to increase the robustness of the operation. Also, to study if variants of infrastructure projects have a quantifiable influence of the punctuality which can be attained in real-life.

Simulation is the obvious method for these kind of studies, because of the complexity of the network, the dynamic and heavily interrelated behavior of train operations and the stochastic characteristics of disturbances.

In the following sections, both DONS and the DONS-Simulator will be described in more detail.

5 DESIGNER OF NETWORK SCHEDULES (DONS)

The DONS system supports the generation of network-wide regular interval timetables and the planning of platform use in large stations. The heart of the DONS system is formed by two solvers, which address the two problems respectively. A graphical interface enables the user to build problem definitions and gives feedback on the solutions as calculated by the solvers. A database system manages the large number of variants that is to be studied, and stores the solutions as well.

5.1 Network Timetable-Planning Concepts

First the user enters and edits an infrastructure project, using the graphical interface. Next the user 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 behavior 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 user can override any of these calculated values for a specific train service or at a higher default level. The user also 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 (supposed to be constant) and halting times (may be variable), plus possibly a maximum travel time between the end stations (to obtain sufficient quality for express trains), 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 large stations; 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.

5.2 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.

6 THE DONS-SIMULATOR

6.1 Templates

To determine the robustness of the timetable a simulator had to be developed, that was able to study the propagation of small disturbances through the network. Because the modeling of the infrastructure is highly generic and had to be easy-to-change, a template was built for the construction of the DONS-simulator in the Arena simulation environment (Pegden, Shannon, and Sadowski 1995), one of the first simulation environments to incorporate the template technology. A template is a collection of user-defined, re-usable modeling building blocks, which are created by programming their functionality, interface, animation and performance indicators. The use of templates has the following advantages (Pater and Teunisse 1997):

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 in 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, containing four building blocks.

6.2 Modeling Infrastructure

The blocks “Timetable Point” and “Connecting Track” model the infrastructure. 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 defined within the Timetable Point.

Timetable Points are linked by one or more “Connecting Tracks”. Travelling through the network, trains are separated (on exit and on entrance of each Timetable Point) by the minimum headway time, which is also specified for each Connecting Track.

The level of abstraction of the infrastructure representation and of the safety system in the simulation model is directly 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.

However, 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 of the robustness of the timetable.

Disturbances propagate only when trains interact. In the DONS-system, some of these interactions are modeled, such as connections between trains and conflicting routes. For simulation purposes, some extra 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.

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 concepts of the building blocks apply 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.

6.3 Definition of Simulation-Scenario’s

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.

6.4 Animation

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 modeled infrastructure. By the color 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 color as the train with the largest amount of delay that is present within the Timetable Point. A typical picture of the animation is shown in Figure 1.

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 AN INTEGRATED DECISION SUPPORT SYSTEM

To test the functionality of the DONS-Simulator, a simulation model was built, using the developed template. The simulation model contains about two-third of the total Dutch infrastructure. When building the model, the users discovered that a lot of time was spent defining the infrastructure and copying data that was already present in the DONS-database.

The DONS-database 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.

To decrease the model building time Railned decided to link the DONS-simulator to the DONS-database and generate simulation models directly from this database. This would also make the verification of the model

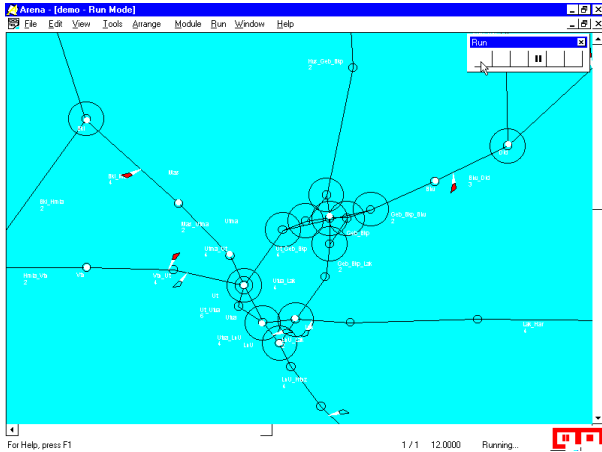


Figure 1: Animation of the DONS-Simulator

implicit. In Figure 2 the architecture of the resulting DSS is shown.

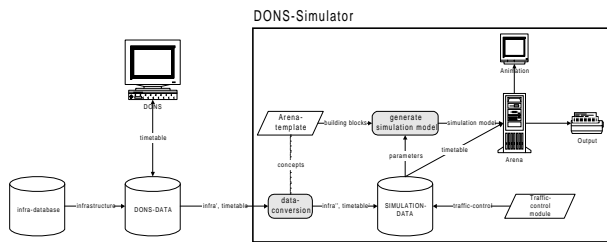


Figure 2: Architecture of DONS and the DONS-Simulator

The template technology enables us to generate simulation models directly from a database. 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 visualize the generated output as soon as the simulation has ended. In this way a thorough analysis can be carried out retrospectively. Examples of these visualizations are the time-distance and track occupation diagrams (Figure 3).

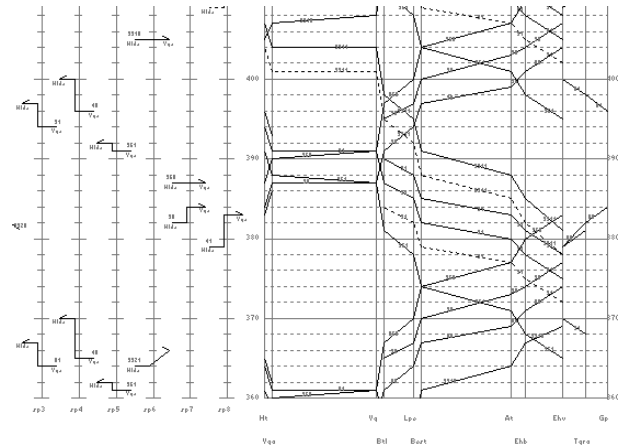


Figure 3: Time-Distance and Track Occupation Diagram – Plan and Realization.

8 EXPERIMENTATION

A first version of the DONS-simulator will be realized by the end of 1998. The main objective of this simulator is to be able to study the relation between the resulting punctuality and the design parameters of the timetable.

The simulator will also be used to evaluate the infrastructure investments between 1990 and 2000, in terms of their effect on punctuality. To this end, the actual situation of the year 2000 (cost, modal split, services offered, quality or punctuality of services etc.) will be compared with a hypothetical situation, the year 2000 without these investments.

Analysis of real-life data will be very important, both for the simulator input – for instance, what is the size and distribution of small initial disturbances – and for the validation of the model. Furthermore, there is little quantitative data on the relative contribution of the effect of small disturbances to the overall punctuality.

9 RESULTS AND CONCLUSIONS

Already a fully operational prototype of the DONS-simulator has been built last winter, partly integrated with the DONS-system. This prototype will form the basis for the first version of the DONS-simulator that will be realized by the end of 1998. 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 station routing. Building blocks have to be designed to model the infrastructure within a station. The concepts of the Rail-template, as described in Pater and Teunisse (1997), 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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