Potential of Microscopic Timetable Design in the Netherlands

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This paper deals with real-world plannings problems of timetable design. Improving the timetable design methodology results in a more reliable timetable and a higher quality for passengers.
This research first identified the Dutch timetable design process. Afterwards the weaknesses of the Dutch timetable design methodology is identified. These identifications are made by conducting interviews within NS & ProRail.
In the third section a case study is conducted. The Dutch 2014 timetable is simulated and compared with a conflict-free timetable which was constructed using microscopic methods (planning in seconds instead of minutes and headways calculated by blocking times instead of plan norms). The simulations resulted in 37% less conflicts and a decrease of 8% delay.
Further research is recommended to validate the conclusions in this paper and to investigate the practical usability of a microscopic methodology in an actual design process.
This paper is a shortened version of the Master thesis of Planting (2016).

Keywords: railway, timetabling, blocking diagram, microscopic

1. INTRODUCTION

Timetabling is one of the major planning tasks in railway traffic and becomes increasingly complicated with the increasing demand for more service. Timetables need to provide accurate time-distance infrastructure slots or train paths that secure conflict-free train runs. Moreover, the plan must cope with the daily stochastic variation during operation.
The expected growth of passenger kilometres in the Netherlands is 1.6-2.7% per year (KiM, 2015). The improvement solutions for more capacity are among other in more efficient use of the current capacity of the rail tracks (ProRail, 2015). One of the quality measurements of a timetable is the punctuality of the train service. The yearly 5 minute punctuality in the Netherlands is 94%. Worldwide only three other countries (Austria (96%), Switzerland (97%) and Japan (98%)) achieve higher punctualities (NS, 2013). The challenge for railway companies is to deal with the increasing demand while maintaining the quality of the timetable.
This paper has three aims. First, the aim is to identify the current timetable design process. The second aim is to identify the weaknesses in the timetable design methodology in the Netherlands. Third, the aim is to invest the potential of microscopic timetable design in the Netherlands. Information for the first two aims is retrieved from interviews with 16 employees of NS and ProRail, Dutch manuscripts of these interviews can be found in Planting (2016). The third aim is investigated by using two timetable design programs.
The scientific relevance of this paper is that this is the first scientific description of the Dutch timetable process and one of the first investigation of the differences between a macroscopic- and a microscopic timetable. The social relevance of this paper is that another method could lead to a more stable train service with less delays.

2. CONTEXT

In history, the last two major changes of the Dutch timetable were in 1970 and 2007 (Veenendaal, 2008). Kroon et al. (2009) describes the main changes in the timetable and the use of Operations Research (OR) in the design of the new 2007 timetable. Assad (1980) presented the first overview of the use of OR in timetable design. The most recent overview is given by Huisman, Kroon, Lentink, and Vromans (2005) and by Cacchiani and Toth (2012).
This paper focuses on methodological choices of timetable design, needed as input for the OR issues. A recent framework is given by R. M. P. Goverde et al. (2016). Goverde et al. present a performance-based railway timetabling framework using an integrated approach on three levels: microscopic, macroscopic and a corridor fine-tuning level. The most important levels are the microscopic and macroscopic level. In these levels a distinction is made in the level of detail of *Infrastructure, timing and calculation of headways* (R. M. P. Goverde et al., 2016).

A distinction between microscopic and macroscopic infrastructure data is given by Bešinović, Quaglietta, and Goverde (2015). As represented in Figure 1, the microscopic representation considers homogeneous behavioural sections (sections with constant values for permissible speed, gradient and radius) and nodes for points where these behavioural sections changes and some operational information like routes, alternative platforms and timing points. The macroscopic representation considers nodes in a macroscopic network which are referred to timetable points, like stations and junctions.

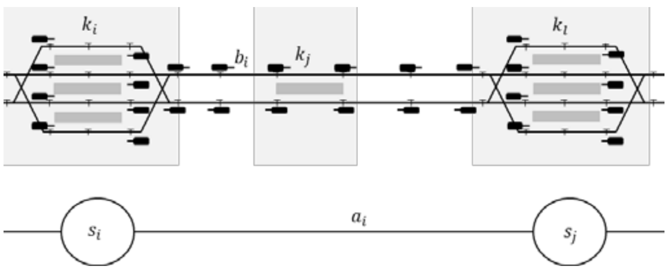

Figure 1. Microscopic (top) and macroscopic (bottom) data of infrastructure Bešinović et al. (2015)

Based on the infrastructure data and the characteristics of the trains, the technical minimum running times are calculated. Next to these technical minimum running times, a running time supplement is added. The typical time supplement is 3%-7% for European railways. The running times, headway times and dwell times are an important part of the timetable (Hansen & Pachl, 2014). The microscopic and macroscopic level of detail of the times in the timetable are very different per country. Most countries make a differentiation between a timetable for internal use and a timetable for passenger use (rounded to whole minutes). For example, in Switzerland the internal timetable is in seconds (Scheepmaker, 2016b), in Austria in 1/10 minutes (Scheepmaker, 2016c), in the United Kingdom (UK) in 30 seconds (Scheepmaker, 2016a) and in the Netherlands in whole minutes, therefore, there is no difference of timetable for passenger use in the Netherlands (ProRail, 2016).

Table 1

Headway norms in minutes of two trains in the Netherlands (ProRail, 2016a).

Activity 1^{st} train	Activity 2^{nd} train			
	A	P	S	D
Arrival (A)	3	2	3	n.a.
Passage (P)	3	3	3	2
Short Stop (S)	4	4	4	3
Departure (D)	4	4	4	3

Besides distinction in microscopic or macroscopic detail of infrastructure and timing, there could also be distinction between the headway times. The macroscopic method is based on norms and this is done in the UK and the Netherlands, where in the UK a distinction is made between passenger trains and freight trains (Scheepmaker, 2016a; ProRail, 2016a). These norms are represented in three tables: *follow-up norms, headways for trains in the same direction and headways for trains in different directions*. The table of follow-up norms in the Netherlands is represented in Table 1. Depending on the activity of the two trains in the timetable points, there is a different headway.

The microscopic method to deal with headways is the blocking times: the actual occupation time of a section/block. The successive blocking times per train over a corridor represent a so-called blocking time stairway. Blocking times are computed using blocking time theory (Hansen & Pachl, 2014). The blocking time of a single block section depends on the block length, the train legth and speed, and the signalling and train protection system. The blocking time of one block consists of a setup time, sight and reaction time, the approach time to the block section over at least the braking distance, the running time in the block, the clearing time in which the train clears the block over its entire length, and the release time of the route, see Figure 2.

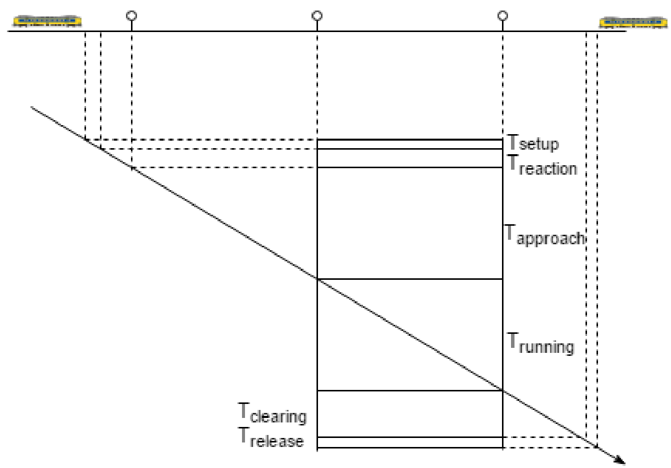

Figure 2. Dependent variables of a block time for a train.

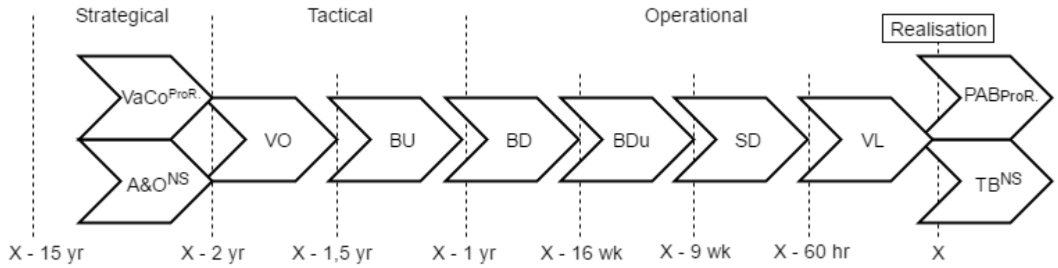

Figure 3. Process of timetable design in the Netherlands.

3. PART 1: TIMETABLE DESIGN IN THE NETHERLANDS

In the Netherlands two main parties are involved in the timetable design; ProRail and NS. ProRail (infrastructure manager) is the organisation that takes care of maintenance and extensions of the national railway network infrastructure, of allocating rail capacity, and of traffic control. NS is the main passenger train operator in the Netherlands. NS provides train services on the Dutch main rail network (*HoofdRailNet*). Next to ProRail and NS, there are seven regional passenger train operators (Abellio, Arriva, Connexxion, Syntus, Veolia, Keolis, DB Regio) and 21 cargo operators (like DB Schenker Rail and HUSA Transporatation Railway Service) (ProRail, 2016b).
The information in this section is retrieved from Planting (2016).

Process of timetable design in the Netherlands.
The design process of a new timetable in the Netherlands is conducted in eight phases, see Figure 3. These eight phases will be discussed below.

VaCo & A&O phase. Within the departments VaCo(*Vervoeranalyse en Capaicteitsontwikkeling* (Transport analysis and Capacity development) ProRail) and A&O (*Advies & Ontwikkeling* (Advice and Development) NS) studies are done to 15 years in advance. In this phase different variants are figured out. ProRail makes these variants for infrastructure improvements and NS makes variants about lines, stops and frequencies. ProRail and NS have contact with each other to be informed of each other plans. To determine the capacity of different variants preliminary timetables are made.

VO-phase. In the VO-phase (*VoorOntwerp*/preliminary design) preparations are made for a specific timetable. Preliminary studies are exploratory studies into the possibilities and requirements that will be discussed in the next (BU) phase. When there are little changes in the new timetable (like timetable 2014, 2015, 2016, 2018), the timetable of the previous year will be used. If there are many changes in the new timetable (like 2017), A&O & VaCo will deliver a concept timetable.

BU-phase. Within the BU-phase a basic (single) hour pattern (*BasisUurPatroon*) is made, because in the Netherlands a cyclic timetable is developed. The BU-phase is the first phase when the infrastructure can not be changed: on large exception there are small adjustments possible (a new shunting or a platform extension). The basic hour pattern is made in design studios which are attended by every operator and the infrastructure manager. When two operators want to have the infrastructure capacity at the same time, and they do not agree on solutions, an *agree to disagree* is made. An agree to disagree will be solved in the next phase.

BD-phase. In the BD-phase (*BasisDagen*/Basic Days) the basic hour pattern is extend to the whole week (7x 24h) and the start and end of each day is designed. This is done by every operator on individual basis. The final capacity application is done in mid April. ProRail asses the timetable and when there are conflicts between two trains, ProRail will make the decision which of the conflicted trains will get the train path based on the decision rules in the network statement.

BDu-phase. The operators receive the final capacity allocation from ProRail at the start of the BDu-phase (*Basis-Dagenupdate*/Basic Days update). In the BDu phase small adjustments can be made to fine tune the timetable. When these adjustments do no result in a conflict, ProRail will accept them. Besides the first BDu of december, there are five extra moments when amendments (*wijzigingsbladen*) can be implemented (February, April, June, September and October (Autumn measures).

SD-phase. Based on the BDu, a Specific Day (*Specifieke dagen*) is designed, where the BD timetable is extended to the complete period for that specific BDu. Often adjustments need to be made on the BDu for a specific day because of non-periodic infrastructure maintenance and events (concerts, parties and sport).

VL-phase. In the VL-phase (*VerkeersLeiding*/ traffic control) last minute train path orders are processed and routes of the trains are (automatically or manually) set up. Last minute train orders can be for are used for hauling defect rolling stock, last-minute freight trains and empty trains.

PAB & TB phase. When the timetable is executed, ProRail and NS evaluate the quality of the timetable. This is done for every day and for certain specific situations. These evaluations are based on punctuality and on the dispersion of the train service.

Methodology of timetable design in the Netherlands

During the eight phases where the Dutch timetable is designed, a certain methodology is followed. This methodology is equal for NS, ProRail and the other train operating companies. The basis of the Dutch railway timetable is a basic hourly pattern (BHP) over the corridors and a basic platform occupation (BPO) in stations. Almost all train lines (except international trains) operate with a cycle time of one hour or at regular intervals within a cycle of one hour (e.g. 30 or 15 minutes) (R. M. Goverde, 2005).

The timetable design process is based on microscopic infrastructure data. The running times for passenger trains are calculated without slopes, however, freight train running time calculation do take slopes into account. The running times are calculated in 1/10 minutes. The timetable is designed on timing points (*dienstregelpunten*), where the time is rounded to whole minutes, were at least 5% running time allowance is included. The headways between trains are based on norms (see Table 1).

For the timetable design, different software is used. During A&O, VaCo and VO process the system DONS (Designer of Network Schedules) is used. DONS is developed by NS and ProRail. In DONS different versions of timetables can be saved and infrastructure can be adjusted. However, the main timetable design and train path allocation system in the Netherlands is Donna, which is also developed by NS and ProRail. Donna is used by every company which is involved with the timetable design. For each day or period, one file is made. This file can be viewed and adjusted by multiple users at the same time. For specific situations it is possible to make a ROBERTO calculation: in this system the minimum headway times are computed instead of using norms.

Microscopic simulations of the timetable are done by FRISO. Output of the analyses are delays, dispersion, propagation and damping of delays and infrastructure use.

4. PART 2: WEAKNESSES OF THE DUTCH TIMETABLE METHODOLOGY

Despite the high achieved punctuality in the Netherlands, there are four weaknesses in the methodology identified: generic plan norms are not always suitable, a planned timetable in whole minutes is too general, structurally stochastic simulations for robustness analysis is missing and the possibility for speed advices to train drivers is used too little. The information in this section is retrieved from Planting (2016).

1. Generic plan norms are not always suitable. The generic plan norms as presented in Table 1 are not always suitable. These norms are sometimes too low, i.e., in theory there is no conflict, while there is a conflict in practice. Sometimes these norms are too high: in practice there is more time then there is in theory. This is no problem when the intensity is low, however in the Netherlands the intensity is very high. Therefore it would be better if the headways between trains are better representing the reality.

2. A planned timetable in minutes is to general. The timetable is rounded to whole minutes on timing points. This is not practical, for example when there are three timetable points located behind each other; each timing point needs a different time (trains can not be at different locations at the same time). Furthermore, due to the rounding valuable information of capacity is lost.

3. Structural stochastic simulations for robustness analysis is missing. At the moment, there are no structural stochastic simulations used to asses the robustness of the timetable. In practice the train service will not operate exactly as planned due to stochastic behavior during operation: processes have a distribution function and trains are sometimes delayed. To see how the timetable handles these distributions and delays, stochastic simulations needs to be used.

4. The possibility for speed advices to train drivers is used too little. Sometimes a train need to leave a station to clear a platform, but this train cannot enter too fast a new section of station. A speed advice could be used to solve these situations. This solution takes extra time and therefore, this should only be used when no other solution is possible.

5. PART 3: CASE STUDY ARNHEM - NIJMEGEN

To see if there are benefits of solving the four weaknesses of the Dutch timetable methodology (see above), a case study is conducted. This case study is done for the Basic Hour Pattern in the area of Arnhem (Ah) - Nijmegen (Nm), including the first station behind Ah and Nm where all trains between Ah-Nm have a stop (see Figure 4).

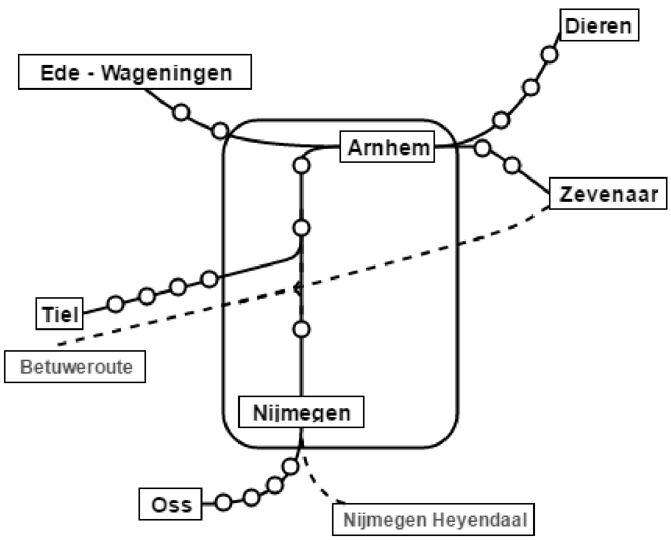

Figure 4. Geographical scope of the case study between Arnhem en Nijmegen.

Ten train lines are active in this area. The ICE is not taken into account, because it is planned in conflict with an *agree to disagree* and this makes analyses difficult. This is not a major problem since the ICE is not operating in the main area (between Ah & Nm) and there is no shortage of platform capacity in Arnhem.
Three programs were used in this case study: Donna, TRENTO and RailSys. Donna is the main Dutch timetabling program, TRENTO is used to produce dispersion or bandwidth graphs of realisation data and RailSys is a commercial available timetable design and simulation software and it is capable of solving the four weaknesses as identified earlier. Currently, RailSys is used by ProRail and NS to gain experience with microscopic planning and simulation tools; RailSys is not used in the timetable design process. RailSys calculates headways based on the blocking time theory. The 2014 timetable is used, because this timetable is already operated, so there is realisation data available, and the infrastructure build in RailSys is based on the 2014 infrastructure. The method of the case can be seen in Figure 5.
A more detailed explanation of this case can be found in Planting (2016).

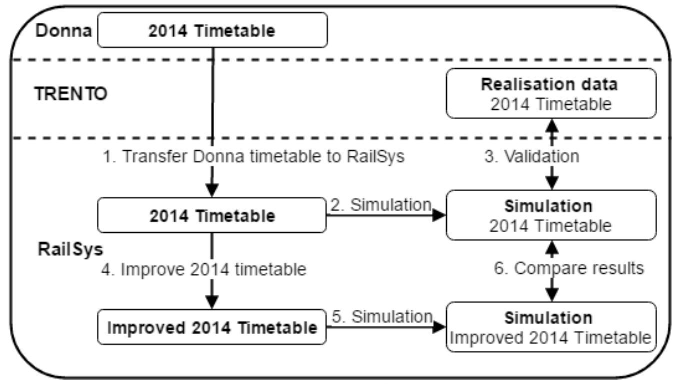

Figure 5. Methodology of the case study.

Step 1: Transfer Donna timetable to RailSys
The Donna 2014 timetable is converted to RailSys in the first step. This resulted in 20 to 70 cases where the scheduled running times are smaller than the technical minimum running times including at least 5% supplements per hour. In total there were 83 unrealisable running times (i.e. scheduled running time is lower than technical minimum running time) per hour.
For headways three microscopic ROBERTO computations are consulted. The blocking time of RailSys are in line with these ROBERTO calculations. RailSys detected seven conflicts which were not detected by the norms of Donna, with a total time of 207 seconds. Donna detected four conflicts which were not detected by the blocking times, since according to RailSys there were 195 seconds available. In total 12 seconds more capacity is used by RailSys. Note: it is unknown which headways were to long, because of the used norms. Therefore, it cannot be stated that microscopic timetable takes more capacity than macroscopic timetable design.

Step 2: Simulate 2014 Donna timetable
In step 2 the 2014 Donna timetable is simulated in RailSys. The trains are simulated for four hours, within this period the simulation has enough start-up time. To approach average values in the stochastic simulations, 200 stochastic simulation runs were executed.
In RailSys it is possible to determine three delays over all sections/stations: dwell time disturbances, departure disturbances and the initial delay. The dwell time disturbances and departure disturbances are based on the parameters of CQM (2015). The initial delay is based values on the dispersion graphs from TRENTO (see Figure 6).
Because it was not possible to determine running time disturbances for all sections (this is only possible for every individual section), the running time disturbances are not divined. Therefore, the dwell time disturbances are defined for one category higher.

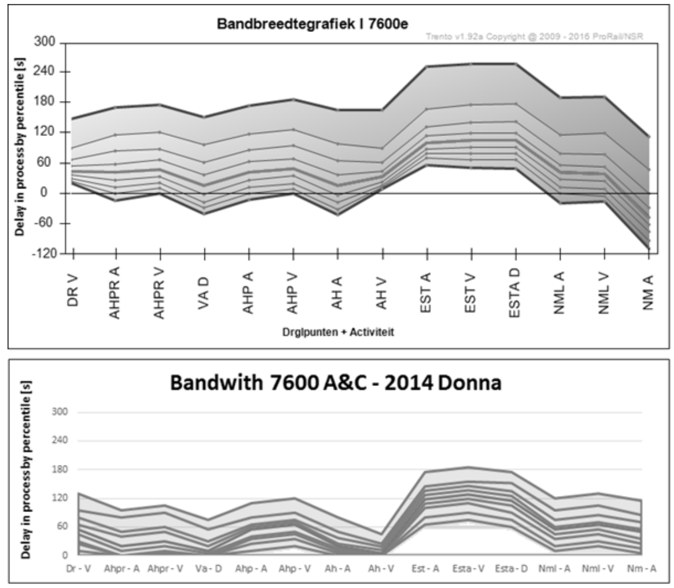

Figure 6. Validation RailSys simulation; the TRENTO realisation bandwidth (top) and the RailSys simulation (bottom).

Step 3: Validate 2014 simulation with realisation

In step 3, the validation of the simulation with the realisation data is done. This is done with the dispersion graphs from TRENTO (see Figure 6). In these graphs the deviation between the timetable and the realisation per 10^{th} percentile of trains is represented. This is done per timing point, where the activity is stated as arrival (A, *aankomst*), departure (V, *vertrek*) or passage (D, *doorkomst*). The 10^{th} percentile (100 %) is not considered since this percentile represents incidental disturbances and delays. From a bandwidth graph, five indicators can be evaluated:

1) Running time shortage:
Lines are increasing parallel (between VA & AHP, see Figure 6). This should not occur because the planned times are to early.

2) (Too) much running time supplement:
Lines are decreasing parallel, and and may end up below the x-axis (between ESTA & NML). When there are delays, it is good to have more running time supplement. But when there is too much, trains can run in front of their path and obstruct other trains; this is undesirable.

3) Conflicts:
Lines diverge (between AH & EST). This is an undesirable characteristic.

4) Dwell time:
Between A & V. Dwell time can be to small (lines increasing parallel) or the dwell time is longer then needed (lines converge) (a small conflict between AH & EST). Dwell times should not be too small, but also not too large.

5) Punctuality boundary:
If all the lines are below 300 seconds, the punctuality of the train service is at least 90% (as in Figure 6). It is desired that all lines are as low possible.

When the bandwidth graphs of the simulation and the realisation are compared (see Figure 6), it can be seen that the main five characteristics can be simulated. Nevertheless, there are some caveats: RailSys cannot simulate trains faster then scheduled, the simulated running times are little faster, and the dwell times are longer than the realisation (because of the simulation settings).

Step 4: Improved 2014 timetable

In step 4, the 2014 Donna timetable is improved. This is done by the following strategy:

1. Lines & stops are equal to the Donna timetable;
2. There are no conflicts;
3. Running times are at least equal to the technical minimum running time and plus maximum 5% running time and 30 seconds supplement;
4. Reserved use of speed advices;
5. Timing points are defined in seconds;
6. Entree and leaving time of the area are equal;
7. Departure time of stations are rounded to whole minutes;

Strategy 1 up to 3 and 5 are applied on all lines. Strategy 4 is applied on seven sections. Strategy 6 was not applied on 4 of the 18 lines, 3 lines were shifted parallel for one minute, 1 line was shifted parallel for two minutes. Strategy 7 is not applied for 4 lines with 12 stops in total, because otherwise it was impossible to achieve strategy 2, 3 and 6.

Step 5: Simulate improved 2014 timetable

In step 5, the improved timetable, which was designed in step 4, is simulated. This is done with the same parameters as the simulations in step 2.

Step 6: Compare 2014 & improved timetable

In step 6, the two stochastic timetable simulations (the 2014 Donna timetable & the improved timetable) are compared. The first part of the evaluation is done with the bandwidths. As can be seen in Figure 7, the bandwidth in the improved timetable is more flatter compared to the bandwidth of the Donna 2014 timetable. This figure also indicates that the total time of the trains in the area is lower (bandwidth at the end station is lower than the first station). These two conclusions can be drawn for all lines.

As a second part of the evaluation, the conflicts between two trains in the two timetables are compared. The average number of conflicts in the simulations (in total 200 runs) can be found in Table 2. In the deterministic runs, there were 51,0 conflicts in the 2014 Donna timetable. The improved timetable had no conflicts: this was expected, because the

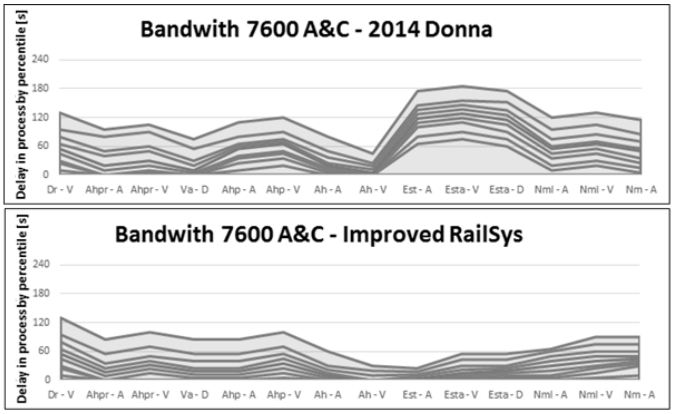

Figure 7. Bandwidth 7600 A& C line of the Donna 2014 timetable (top) and the improved timetable (bottom).

timetable was designed conflict free. In the stochastic simulation, which was validated in step 3, there is a small increase in the amount of conflicts in the 2014 Donna timetable. The improved timetable had a big increase in conflicts: this can be explained by the high occupancy on the infrastructure, where the trains are planned short behind each other (1 minute buffer) and the stochastic processes resulted in dispersions which are larger than 1 minute. It can be seen that in the stochastic simulation, the 7^{th} implemented strategies in the improved timetables led to a decrease of conflicts.

Table 2
Number of conflicts in the simulations (N=200).

	Average number of conflicts	
	Deterministic	Stochastic
2014 Donna timetable	51.0	55.1
Improved timetable	0.0	34.4

As a third part of the evaluation the delays are analysed. The average of *the sum of delays on the timing points* was for the 2014 Donna timetable 13.1 minutes, the improved timetable had an average *sum of delays on the timing points* of 12.1 minutes. This is a decrease of 8%. Because the delay decreases over longer distances in the improved timetable, this gain should be higher when the case study area will be larger. The average maximum delay was for the 2014 Donna timetable 17.7 minutes. In the improved timetable the average maximum delay was 12.5 minutes, this is a decrease of 29%.
Concluding, the train service in the improved timetable was more stable, the number of conflicts decreased by 37% and the average delay decreased by 8%.

6. CONCLUSIONS AND FURTHER RESEARCH

In this paper the current timetable design process and the weaknesses in the timetable design methodology in the Netherlands are identified. Furthermore, a case study is conducted to invest the potential of microscopic timetable design and simulation in the Netherlands.
The Dutch timetable is planned in seven phases and evaluated in one phase. There is one strategical phase from 15 years till 2 years before implementation of the timetable. There are two phases in the tactical period from 2 years till 1 year before implementations and three phases from 1 year to implementation and one evaluation phase.
As identification, four main weaknesses in the Dutch timetable methodology occurred: the generic plan norms are not always suitable, a planned timetable in whole minutes is to general, structurally stochastic simulations for robustness analysis is missing and the possibility for speed advices to train drivers is used too little.
The case study showed the potential of the microscopic method. A simulation of the 2014 Dutch timetable was compared with an improved version. In the improved version, the headways between trains were planned based on blocking times, the timing points were defined in seconds instead of minutes and speed advices were used. This resulted in a conflict free (so feasable) timetable. With the use of stochastic simulations, it can be concluded that the train service in the improved timetable was more stable, the number of conflicts decreased with 37% and the average delay decreased with 8%.
Further research should focus on validation and the practical use of this research. This involves three different studies: first, the simulation in RailSys should be validated in another simulation program like FRISO and/or OpenTrack. Second, the case study should be repeated on another and larger area to see if there are equivalent benefits. Third, the practical usability in the Dutch timetable desgin process should be invested. Therefore, a microscopic timetable tool could be used next to the basic hour pattern process.

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