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# A comparison of different configurations of a Centrally Guided Train Operation System in Dutch Railway Operations

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**Abstract**
Although Dutch train operation is one of the safest in the European Union, safety remains one of the top priorities. On a yearly basis, an estimated 7 million red signal approaches occur on the Dutch railway network for the largest train operating company NS. Out of these 7 million red signal approaches, 3 million red signal approaches are estimated to be caused by small deviations to the planning. As a result of this continuous focus on safety aspects, ProRail, the Dutch rail infrastructure manager, and NSR started a project to empower train drivers with more information on the current situation and near future related to their trains. In a simulation study four train driving strategies were compared in two areas in the network. These strategies, ranked in order of increasing level of driver information quality, are: first is driving at highest allowed speed, second is following the timetable without advisory speed information, third is using advisory speed information without changing train orders and fourth is using advisory speed information with possibility of changing train orders. At each location the timetable has been exposed to three increasing levels of disturbance scenario's. Results show that the advisory speeds strategy (third) reaps a large part of the safety benefits that the fourth (limited Centrally Guided Train Operation) strategy is able to achieve.

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# 1 Introduction

## 1.1 The Dutch Railway Network

The Dutch railway network is approximately 2,800 kilometres long and mainly consists of electrified double-track sections. Implementing regulations of the European Union, ownership of infrastructure and allocating access to the network has been split from train operation. The former is the responsibility of the state owned non-profit organization ProRail. NS Reizigers (NSR) is the largest train operator for passenger transport. In 2015 12 other train operating companies for passenger transport, 17 freight transport and 11 maintenance companies are active on the Dutch railway network. NSR carries well over 1 million passengers on an average working day, with a market share of over 50% during peak hours and between the four largest cities. In 2014, Dutch passengers travelled approximately 17 billion kilometres in NSR trains. Based on these figures, it is clear that passenger railway transportation plays an important role in Dutch society

## 1.2 Train on Line

The European Railway Agency (2013) reported train operation in the Netherlands to be one of the safest in the European Union. However, an accident near the station of Amsterdam in 2012 has emphasized safety as a top priority. As a result of the additional attention for safety, NSR (2014) reported in a decrease of 40% in the number of signals passed at danger (SPADs) over 2014.

Train operation in the Netherlands is based on a timetable that follows an hourly pattern. Typically, safety is taken into account by implementing hard constraints in these patterns, for example by requiring a minimum headway time between two subsequent trains sharing the same track. The quality of such a timetable is typically evaluated on punctuality measures and energy efficiency. However after 2012, safety aspects also came into focus. In both the planning and the operational stages, stronger checks and safety measures have been implemented.

For the planning stage, this means amongst others that trains should be planned using feasible running times adopted from data of the realised operation. For the operational stage this means that train drivers and train guards should try to stick to the planned running and dwell times as much as possible. Because these times and the train movement are represented by a line in a time-distance diagram, this means that the train crew tries to keep the train on its line. Therefore, the train drivers need more, more detailed and actual information about train status and timetable. To enable the train crew to keep the train on its line, the search is for the right information at the right time given an unchanged timetable planning. The train driver interprets this information and possibly adapts his behaviour. In case of small deviations, the driver can proactively prevent a non-commercial stop. In a next step, ProRail and NSR foresee more benefits when also changing orders of trains for crossing movements, using route and track alternatives and adapting route setting moments are taken into account.

# 2 Problem description and simulation approach

## 2.1 Problem description

Traditionally the main benefits for train operating companies and infra managers are punctuality gains and improved energy efficiency. Safety improvements are typically noticed afterwards. However at ProRail and NSR, these safety improvements are the main goal for this study.
On a yearly basis, an estimated 7 million red signal approaches occur on the Dutch railway network for NSR.

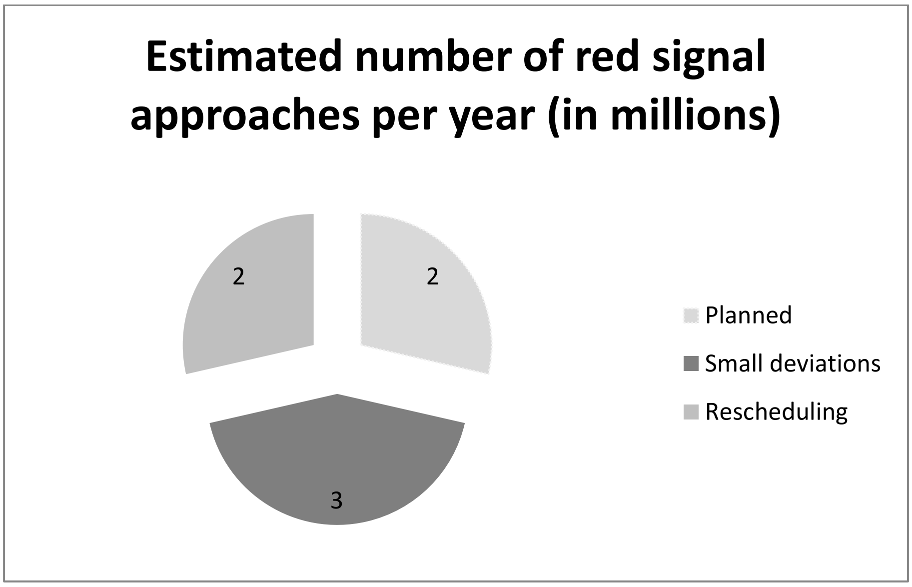

Figure 1: Estimated number of red signal approaches in The Netherlands

Out of these 7 million red signal approaches, 3 million red signal approaches are estimated to be caused by small deviations to the planning. The Train On Line project aims at these 3 million red signal approaches. Every time a train driver prevents approaching a red signal is one less possibility for SPAD.

As a result of the additional attention on safety aspects, ProRail and NSR started a project to empower train drivers with more contextual information on the current situation and near future related to their trains. In addition to the signals outside and timetable information of his or her train, the so-called RouteLint shows the status of upcoming infrastructure blocks (i.e. allocated to current train, planned for current train, allocated for another train, or planned for another train). If infrastructure is allocated or planned for another train, the RouteLint shows the train number and delay information for this train. Albrecht and Van Luipen [2006] report on simulation results of 15 drivers with the RouteLint system, while a subsequent study by Albrecht et al. [2006] describes results of a pilot in real life.

The information provided by RouteLint can also be combined with other data sources to result in some form of speed advice for the train driver. These data sources include amongst other train characteristics, track characteristics, and strategies for energy efficient train operation. The advantage of providing a speed advice over contextual information is that the first requires little to no interpretation by the train driver. The speed advice could be applied on two levels. The first is a local train level where only the actual information of the actual train is used in calculating the speed advice. A second level is an advice where information of all other trains in the vicinity influences the speed advice.

In this respect, the European ON-TIME project assessed the state-of-the art of Driver Advice Systems in Europe (2013). It investigates common problems with the introduction of advisory systems including ignoring the advice, distraction, and over-reliance. Other aspects that are listed in this project are system clusters (location of speed profile and advice definition are performed), the form of the advice (explicit speed, contextual information, other), frequency of updates of the advice, driver-machine interface (visual and/or aural).

Scheepmaker (2013) provides more details on the calculations and mechanics of speed advices in the Netherlands. In a subsequent paper, Scheepmaker and Goverde (2015) compare a robust timetable with efficient train control from the perspective of energy efficiency for a specific line in the Netherlands.

Of course, these centrally computed speed advices provide ample opportunity for a Centrally Guided Train Operation System (CGTOS). A CGTOS could also provide computerized support for the dispatchers of ProRail, detecting conflicts and resolving them (for example by reordering trains on tracks). Since dispatchers and train drivers work for separated organizations, decision support for both drivers and dispatchers by an integrated CGTOS is complex to implement. Therefore, NSR and ProRail decided upon the following incremental approach:

1. Provide train drivers with contextual information by implementing RouteLint.
2. Provide speed advice for train drivers.

3. Supporting both train drivers and dispatchers by implementing a CGTOS.

Note that in these steps we keep in mind that the European Rail Traffic Management System (ERTMS) will be implemented in the future.

In each step, several options for configuring the need for information and decision support for the railway operations exist. Therefore, the benefits of several variants of a CGTOS have been investigated by a simulation approach. In this approach the microscopic simulation tool FRISO (Flexible Rail Infrastructure Simulation of Operations) is connected to the Traffic Management System (TMS) software/application that models a CGTOS and optimizes the train traffic dynamically, see Mazzarello and Ottaviani (2007) for more details. FRISO models railway infrastructure, timetable, rolling stock and train control processes. The TMS provides the driver with information in several levels of quality.

In this paper the focus is on performance defined by safety criteria: the number of non-commercial stops and number of signals passed by a constraining speed and braking aspect at unexpected locations.

## 2.2 Simulation of a Centrally Guided Train Operation System

The use of a traffic management system, that minimizes the scatter in the operation and provides actual information about upcoming conflicts and system performance, might help to keep the operations as close as possible to the planning/timetable. The methods and algorithms were originally developed in the EU funded COMBINE project for a railway system using flexible and moving (safety) blocks. To make it applicable for a real life pilot TMS was adapted to work in a fixed block safety system like the Dutch NS'54-system in the EU funded COMBINE 2 project. The pilot "Green Wave" ("De Groene Golf" in Dutch) proved potential benefits in punctuality level, energy consumption and preventing non-commercial stops. Middelkoop, Mazzarello and DeVries (2013) report on the improvement and potential benefits of applying Traffic Management System (TMS) to optimize train traffic at constrained capacity conditions on an important node in the Dutch railway network. Given the actual positions of the trains, their actual speed, the timetable time and track targets and a cost function, this system continuously predicts upcoming conflicts and generates a new feasible (and safe) timetable in real time accompanied by conditional driver advisory speeds for each train. This model is connected (via the IEEE High Level Architecture protocol) to FRISO. To enable the comparison of several driving and traffic control strategies, TMS has been adapted. The combination of TMS and FRISO is a CGTOS simulator that enables the investigation of a number of strategies using more or less degrees of freedom to change train orders, track occupation and timing of train events.

## 2.3 Simulation of driving and traffic control strategies

For keeping the train on its planned line, four control strategies were applied:

1. Drive as fast as possible. Here the train driver tries to drive at the highest allowed speed (by the safety system and rolling stock).
2. Follow the plan. Here the train driver tries to follow the planned timetable without speed advices. Depending on the delay, the train driver estimates a speed such that the next activity of the train will be executed in time, were it is assumed that the train driver is experienced (speed estimate is accurate). Of course, the train cannot drive faster than allowed. Additionally, the train should not drive unrealistically slow, so the train also must drive faster than a minimum speed (about 0.8 * maximum speed).
3. Advisory speeds. Here an advisory speed for each train is calculated, based on the current traffic situation in the whole area, including disturbances. TMS first calculates a new feasible plan, and next calculates advisory speeds based on this new plan. TMS is allowed to use advisory speeds only.
4. Limited CGTOS. Here, in addition to the previous strategy, TMS also controls route booking times and is allowed to change the order of trains. Changing the routes of the trains is still out of scope, even though TMS is able to use alternative routes.

The first two strategies are static, i.e. real time information on the execution of the timetable is not used. The latter two strategies do use this information to prevent conflicting train movements as much as possible.

These simulation scenarios show upper bounds for the benefits. When a CGTOS is implemented the question rises if all benefits can be realized. All simulation scenarios assume that trains are able to respond to given speed advices. The calculated speed advices are optimal. In the simulation all required information about train positions and train statuses is accurate and always available. To explore the influence of train position accuracy and of not responding trains, two additional simulation scenarios were defined, based on Limited CGTOS:

5. Section based train position determination, where train positions are not given by a GPS, but by information of the safety system.
6. 40% of the trains are not able to follow its given speed advice (which the CGTOS knows in this case). This scenario represents the situation where not all trains might be able to receive and respond to the speed advices or drivers may decide to not follow the advice and TMS is aware of this.

## 3 Experiments and results

### 3.1 Introduction of simulated areas and disturbance levels

The simulation approach consists of research on two locations in the Dutch railway network. The first area is centred around the station of Schiphol Airport, depicted in the upper part of Figure 2.

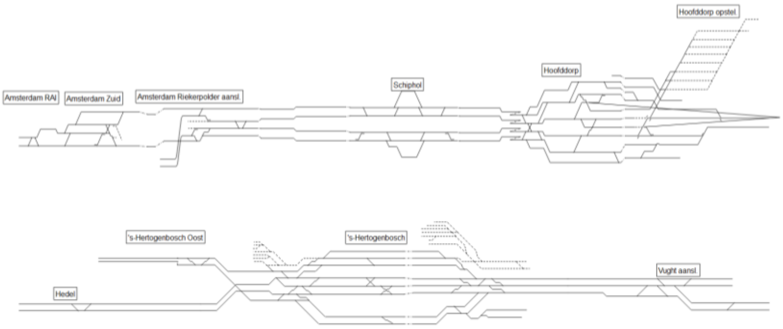

Figure 2: The Schiphol Airport and Den Bosch stations in the Netherlands.

A high number of trains follow each other in a four track tunnel with six platform tracks. This section is a capacity bottleneck in the network. The second location is centred around the station of Den Bosch, depicted in the lower part of Figure 2. Here, two important passenger corridors cross each other and are mixed with freight traffic. Both simulated areas also include the feeder lines toward these stations. The following table gives some more characteristics of these areas:

| Area | # Platform tracks | # Trains per hour | Distance from border to station |
|---|---|---|---|
| Schiphol Airport | 6 | 42 | 9 km |
| Den Bosch | 6 | 24 | 17 km |

Table 1: Some characteristics of the simulated areas

The number of platform tracks is an indicator of the complexity of the area. The number of trains per hour shows the crowdedness at the tracks, while the distance from the border of the simulated area to the station is an indicator for the flexibility that the CGTOS simulator has to solve conflicts.

For each area the timetable has been exposed to three increasing levels of disturbance scenarios:

1. Measured disturbances during normal operation. Distributions were fitted on these measurements and used to generate disturbances in the simulations. Disturbances on entry times and dwell times were used.
2. About 1.25 times the measured disturbances.
3. About 1.5 times the measured disturbances.

The increased disturbances were used to get an indication about the impact of heavier disturbances on the results of the different control strategies.

### 3.2 Computational results

For each combination of an area, disturbance level, and control strategy, we simulated 20 runs of 5 hours, where the first hour is used for warming up and is not included in the results. Moreover, for a given combination of an area and a disturbance level, each train in each of the four control strategies receives exactly the same input disturbance.

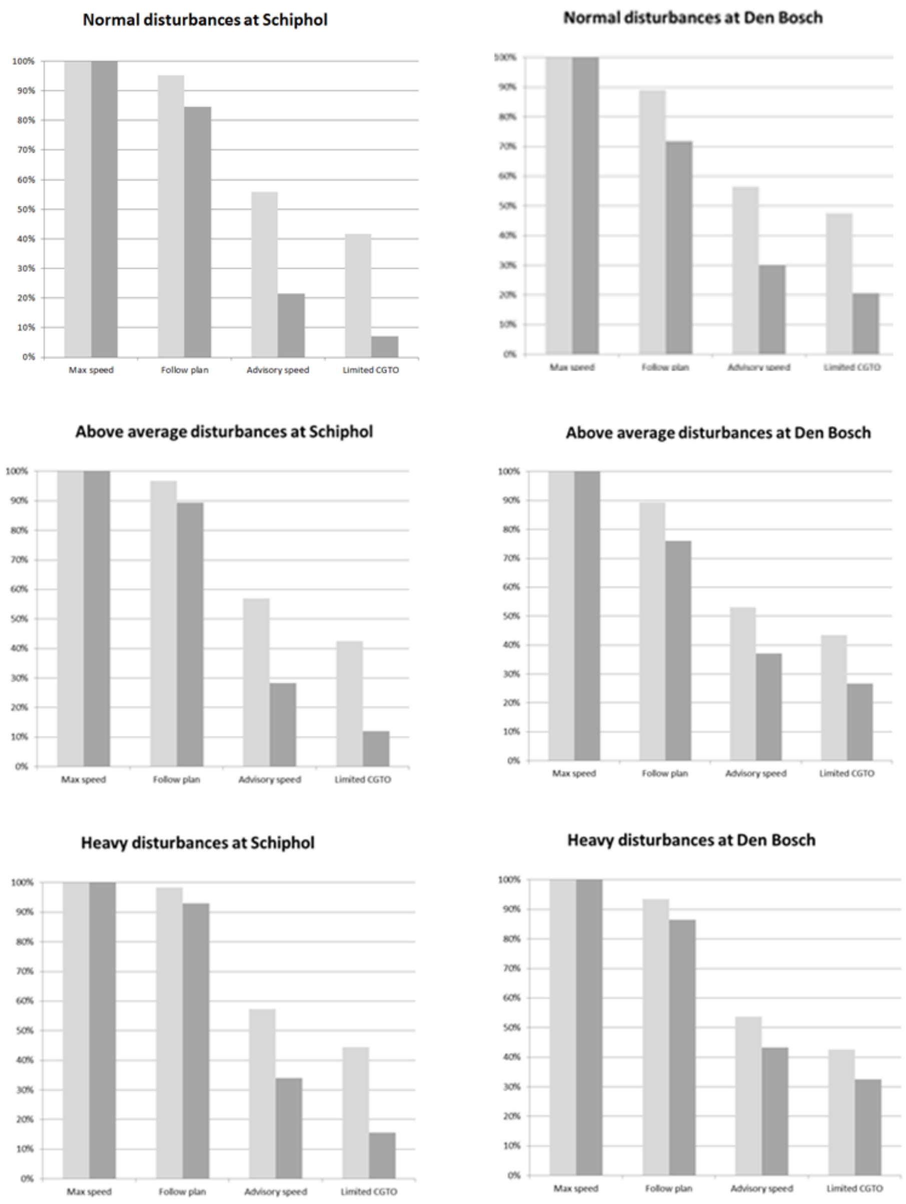

Figure 3: Computational results of the different driving and control strategies for different levels of disturbances at Schiphol Airport and Den Bosch.

Figure 3 summarizes the computational results for the first four control strategies introduced in Section 2.3. These strategies are applied at Schiphol Airport and Den Bosch and for the three levels of disturbances. For each of these 24 cases, we report the normalized number of red signal approaches in the light grey bar and the normalized number of non-commercial stops in the dark grey bar. These indicators are used to represent the safety benefits of the control strategies. These numbers are normalized with respect to the Max Speed strategy, i.e. this strategy is the baseline.

In each of the 6 combinations of area and disturbance level, TMS performs well with respect to red signal approaches and non-commercial stops. In addition, the figure consistently shows that in all cases the normalized number of non-commercial stops is lower than the normalized number of red signal approaches. For absolute numbers this is trivial, but this is not the case for normalized numbers. Moreover, the dynamic strategies Advisory Speeds and Limited CGTOS show impressive results for both indicators, especially for Schiphol Airport. The performance of the Advisory Speed strategy supports our incremental approach of Section 2.1. Finally, at Den Bosch the Follow Plan strategy is more successful than at Schiphol, both in terms of non-commercial stops as well as red signal approaches. This might be caused by the larger geographical area that is covered.

In addition to these results, we also performed the sensitivity analysis described as scenarios 5 and 6 in section 2.3. The corresponding results are introduced in Figure 4, where the Max speed strategy is incorporated as a baseline.

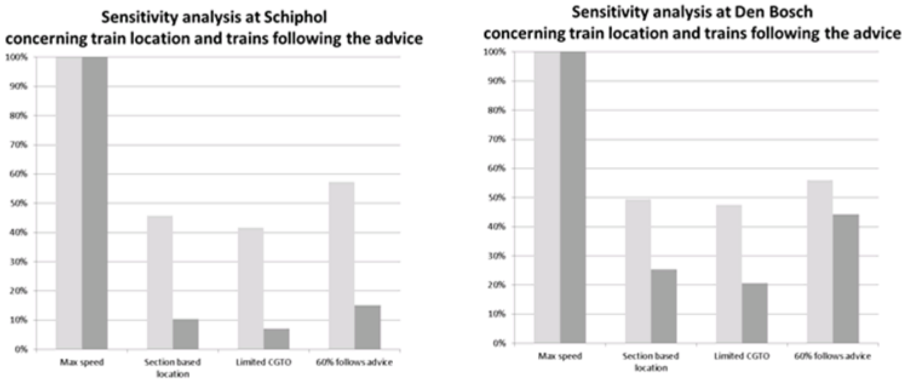

Figure 4: Sensitivity analysis concerning less accurate data on train locations and on the fraction of trains that follow the generated advisory speed

These results show that the number of red signal approaches is not very sensitive for less detailed train positions or the number of trains that follow the advice. However, the number of non-commercial stops doubles when a significant part of the trains does not follow the advice. Once again, this strengthens our initial beliefs that starting with support for the train driver already leads to a large part of the safety benefits. Finally, we note that these advanced dynamic strategies perform better at Schiphol than at Den Bosch.

## 4 Future research

In future research, we will test several of the above strategies in practice during a pilot stage. This should give us important success factors for an implementation in practice as well as improvements on the CGTOS simulator.

Although the areas of Schiphol and Den Bosch show consistent results, we are also working on the application of the introduced strategies to the area of Zwolle, which is an important node where main train lines interfere with regional lines.

Currently we focus on safety as the one and only goal in the CGTOS simulator. In future research, we would like to explicitly incorporate effects on track capacity, eco-driving, and punctuality. These goals are likely to be highly correlated, but exact relations are not known.

Finally, we are working on a more refined implementation of the behaviour of the individual drivers.

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