CONTROLLING OPERATIONS OF PUBLIC TRANSPORT TO IMPROVE RELIABILITY: THEORY AND PRACTICE

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Abstract

RandstadRail is a new light rail system between the cities of The Hague, Rotterdam and Zoetermeer in The Netherlands. During peak hours, the frequency on some trajectories is about 24 vehicles an hour. Dealing with these high frequencies and offering travelers a high-quality product, in terms of waiting times and the probability of getting a seat, the operator designed a three-step controlling philosophy. The first step is to prevent deviations from occurring: the infrastructure is exclusively right of way as much as possible and at intersections RandstadRail gets priority over the other traffic. RandstadRail stops at every stop and never leaves before the scheduled time. The second step in the philosophy is dealing with deviations by planning additional time in the schedule at stops, trajectories and terminals. Small deviations can be solved in this way. The final step to get vehicles back on schedule is performed by the traffic control centre: they have a total overview of all vehicles and they can respond to disturbances like slowing down vehicles nearby a delayed vehicle. Experiencing major disturbances rerouting and shortening of lines is possible.

RandstadRail has been in operation since 2007. The actual data of the performance is used to analyze the actual effects of the control philosophy. It is shown that due to the applied measures the variability of the driving times is reduced, whereas punctuality has increased. This leads to a higher level of service, creating shorter travel times and a better distribution of passengers across the vehicles.

1. INTRODUCTION

In the west of The Netherlands, the region in and around the cities of The Hague and Rotterdam, a new light rail system has been developed: RandstadRail (*1)*. This is a new regional public transport system with high quality standards: high frequencies, fast, comfortable and reliable. RandstadRail replaces and connects former tram, metro and heavy rail lines. RandstadRail consists of two main networks (illustrated in figure 1):

1. The tram lines 3 and 6 in The Hague are connected to the former heavy rail line in Zoetermeer (called “Zoetermeerlijn”). HTM, the public transport company of The Hague operates theses lines;
2. The secondary, former, heavy rail line between The Hague and Rotterdam (called “Hofpleinlijn”) is connected to the metro network in Rotterdam. The public transport company of Rotterdam (i.e. RET) operates this line.

The focus of this research is on the Zoetermeerlijn: the connection of the tramlines of The Hague with the former heavy rail line in Zoetermeer. This network consists of two lines, one of 33.4 km and 41 stops and one of 26.8km and 31 stops. This paper describes possibilities to improve reliability during the planning stages as well as during the operational level. In literature, a lot of attention is paid to operational solutions (e.g. *2,3,4)*, while there are many possibilities at the network and timetable planning stages as well (e.g. *5,6)*. This paper combines both methods.

2. THE URGENCY OF CONTROLLING OPERATIONS

Before the start of RandstadRail, the public transport in The Hague was not controlled in a sophisticated way: The driver knows the departure time at the first stop and the arrival time of the last stop. During the trip some deviations will occur: this results in a distribution of driving times (*6)*.

The deviations of the number 3 and 6 tram lines during rush hours are illustrated in figure 2. This figure shows a distribution in deviation of 3 minutes at the first stop and approximately 10 minutes at a stop in the city centre of The Hague.

RandstadRail between The Hague and Zoetermeer is operated by two lines, both offering 12 trips an hour in both directions, during peak hours. This results in headways of 2.5 minutes on the shared part. Besides, in the city centre, regular trams operate on the same track as RandstadRail: two lines with a frequency of 6 and 8 vehicles per hour per direction. Because of these high frequencies, deviations as shown in figure 2 are unacceptable. This research deals with the minimization of these deviations to reach schedule adherence or regularity. This is necessary because of two main goals:

- *To offer high service quality*
  In the case of public transport service with high regularity and a uniform arrival of passengers at a stop, the probability of having a seat is maximized. Regular arrivals of vehicles prevent a poor distribution of passengers over the vehicles: a mix of empty vehicles and overloaded vehicles.
  Besides maximizing the probability of having a seat, the waiting times are minimized in the case of high punctuality and regularity (*7)*.
- *To prevent congestion*
  On some parts of the RandstadRail lines, signaling is applied. On these parts, capacity is limited, compared to the non-signaled parts. On the busiest parts of the line, the total frequency of all lines (tram and RandstadRail) is approximately 40 vehicles per hour in both directions. The capacity of the infrastructure is sufficient, if regular services are assumed. If substantial irregularity occurs, vehicles will be delayed, because of congestion.

Bunching of vehicles ought to be prevented. To achieve this, attention needs to be paid to preventing deviations next to curing afterwards.

RandstadRail must become a highly reliable regional public transport system. To achieve this, the transport authority also demands quality standards. These threshold values, related to reliability, are (*8)*:

- Maximum 0% of trips is ahead of schedule;
- Maximum 5% of trips has a delay of more than 2 min;
- Maximum 1% of trips has a delay of more than 4 min.

Without additional measures, these values are not achievable, regarding the current punctuality and planned high frequencies. Measures should be taken at both the planning and the operational level. The next paragraph will describe these measures in detail: the control philosophy.

3. CONTROL PHILOSOPHY

As stated in the former paragraph, variety in driving times and deviations of the timetable must be prevented. To achieve this goal HTM designed a new, three-step control philosophy. Figure 3 illustrates these steps, which are described in more detail below.

3.1 Step A: Preventing

The first step is preventing the deviations from occurring. This is the most important step: An ounce of prevention is worth a pound of cure. Different ways exist to avoid deviations. For RandstadRail the following adjustments are applied:

3.1.1 Improvements of infrastructure

An important cause for deviations is infrastructure. RandstadRail consists of two different parts: the former tramway and the former heavy railway. The latter is 100% own right of way without any crossing of other traffic, whereas the former tram part has crossings and shared use of lane. A great deal of the RandstadRail infrastructure has been improved: the shared use with other traffic has decreased, several crossings have been closed and priority at intersections has also improved. This won't prevent all deviations, but it will decrease significantly. Besides shared use of lanes with cars, RandstadRail shares some tracks with other modes of public transport too. At intersections, RandstadRail has priority over other tram lines.

3.1.2 Punctuality shown to the driver

To increase the sense of urgency of schedule adherence for drivers, real-time information of the punctuality is provided in the cabin. This display is presented in (*1*). The delay is shown in quarter of minutes, supported by a background color that changes depending on the vehicle being too early, on time or too late. This information helps the driver to depart on time at the first stop and prevents him from departing ahead on schedule during the trip. If the vehicle is delayed, the driver can try to speed up by using the slack time in the schedule (e.g. using a shorter dwell time).

3.1.3 On time departure

At the moment, schedule adherence is not sufficient (as figure 2 illustrates). Both the starting point and the stops along the line require attention.

To achieve a high level of punctuality, which is required for RandstadRail, significant delays at the start of a trip are unacceptable. One of the main causes of unreliability is poor punctuality at the starting point. The following aspects have an impact on on-time departure and are important for RandstadRail:

- The vehicle is ready to start on time at the first stop. Therefore it is necessary to ensure a high level of punctuality and enough slack layover time;
- The driver is ready to start on time at the first stop. If a driver is not present at some point before the scheduled departure time, the central dispatching room is alerted by the control system. They decide how to resolve this (e.g. contact the driver, use a spare driver);
- The departure time of the next trip is shown to the driver of the vehicle as well as to the drivers in the waiting area;
- It is important to plan an achievable driving time. If not, the driver will adjust his departure time to reach the endpoint on time. The driver must trust the timetable. Excellent training is essential;
- The central dispatchers are warned by the control system if the delay of a vehicle on the first stop exceeds a certain threshold;
- The schedule adherence is continuously monitored and the data is provided to the management, the dispatchers and, especially, to the drivers.

RandstadRail vehicles are not allowed to leave ahead of schedule at any stop. Driving ahead of schedule creates deviations and could lead to bunching of vehicles. This results in a lesser quality level of service: long average waiting times and a high probability of overcrowded vehicles. To prevent drivers from departing early, a display in his cabin shows the deviation of the timetable. When a vehicle arrives at the stop too early it has to extend its dwell time. This additional dwell time will always be short though, since a tight schedule excludes an early departure at the previous stops.

To calculate the effect of the measure mentioned above, a tool is developed to assess the punctuality and additional travel time for passengers if the vehicles leave on time at the first stop and never depart early, compared to normal operations with less schedule adherence. Punctuality is defined as in formula 1.

$$\overline{p}_j = \frac{\sum_i \left| t_{i,j}^{real} - t_{i,j}^{planned} \right|}{n_i} \qquad (1)$$

where:

$\overline{p}_j$ =*average punctuality at stop j*
$t_{i,j}^{real}$ = *real departure time of vehicle i at stop j*
$t_{i,j}^{planned}$ = *planned departure time of vehicle i at stop j*
n_i = *number of vehicles*
j = *stop index*
i = *vehicle index*

Although punctuality is commonly used as a quality indicator, it does not illustrate the level of reliability in the most effective way (*6)*. To exactly show the impact on passengers, a calculation of additional travel time for passengers must be made. Formula 2-4 show algorithms, which are used in this research to calculate the mean additional travel time per passenger on a line. Passengers are assumed to arrive between 2 minutes before the scheduled departure time and 1 minute after (*9)*. If the vehicle doesn't depart in this bandwidth, they incur additional waiting time. If the vehicle is early, they have to wait a complete headway; or else they are forced to wait for an additional period equal to the delay.

$$\begin{cases} ET_{i,j} = H, & \mathrm{p_{i,j}} \le -120 \\ Ei_{i,j} = 0, & -120 < \mathrm{p_{i,j}} < 60 \\ ET_{i,j} = \mathrm{p_{t,j}}, & \mathrm{p_{i,j}} \ge 60 \end{cases} \qquad (2)$$

$$ET_j = \frac{\sum_i ET_{i,j}}{n_i} \qquad (3)$$

$$ET_{stop} = \sum_j \alpha_j * ET_j \qquad (4)$$

where:
$ET_{i,j}$ = *additional waiting time due to vehicle i at stop j*
ET_{stop} = *average additional waiting time per passenger*
H = *scheduled headway*
α_j = *proportion of passengers boarding at stop j*
$p_{i,j}$ = *deviation of vehicle i at stop j*

In a case study (*6*), the effect of not driving ahead of schedule on additional travel time and punctuality is calculated for all tram lines in The Hague, using formulas 1-4. Actual data of passengers and driving times is used and besides the calculation of the actual situation, an assessment is made in which vehicles depart on time and not too early. Table 1 shows the results for tram line 6, which is transformed to RandstadRail. These results show a large increase in punctuality due to on-time departures and no driving ahead of schedule. The effect on additional travel time per passenger is even larger. On average, passengers on this line will benefit from a reduction of almost 40% of additional travel time due to improved reliability.

3.1.4 New dwell process
Besides infrastructure, the dwell process is a significant cause of deviations as well. These deviations can be prevented as well. Important factors are:

- RandstadRail vehicles stop at every stop, like a train system. Constant dwell times in the schedule decrease deviations. In (*10)* the distribution of total dwell time per trip is given for a tram, showing large differences per trip. Differences are mainly caused because of skipping stops or non-constant dwell times. By introducing stopping at every stop the deviation will greatly decrease.
- RandstadRail operates with new state-of-the-art vehicles. The vehicle and platform are at the same level and broader doors enable a smoother way of boarding and alightening. Factors that have a major impact

on dwell times, like trolleys, will have less effect. This way, the new characteristics of the vehicles will eliminate a significant cause of delay.
- Stops are redesigned, creating more space for travelers boarding and alighting.
- Where bus and tram drivers sell tickets and provide information to travelers, RandstadRail vehicles have vending machines. The driver is seated in a closed cabin and no contact is possible with travelers.

3.1.5 New planning process
RandstadRail is a public transport system with characteristics of both a tram and a train. Besides new infrastructure and a new way of operation, this requires a different way of planning as well. Normally, tram lines are planned calculating the total trip time. This calculation is used to estimate the departure time of each stop. To achieve better accuracy, the RandstadRail schedule consists of driving times from stop to stop, such as in heavy railway planning. This way, the schedule will be more accurate and driving ahead of schedule is easier to prevent. Because of the high punctuality standards, an accurate and up-to-date schedule is very important. To improve this schedule, a feedback loop from operation to schedule design is necessary. In tramway planning, this is an often used loop, contrary to heavy railway scheduling.

3.2 Effects of preventing
Figure 4 roughly shows the expected effect of all these changes. The black lines are the maximum current deviations. Improvements of the infrastructure and the vehicle will reduce the increase in deviations (white line). Improving the punctuality at the first stop and preventing vehicles to depart early will decrease deviations as well (grey line).

3.2 Step B: Coping with deviations
The second step in the philosophy is dealing with the deviation by planning additional time in the schedule at stops, trajectories and terminals. Small deviations can be solved this way. Carey (*11)* and Israeli (*12)* deal with this topic as well.

Adding additional time in the timetable enables late vehicles to catch up. This additional time is a trade-off of operational speed and reliability. The larger the slack time, the higher the reliability, but the lower the average operational speed of the vehicles (if vehicles are not allowed to drive early).

The slack time can be added to different parts of the trip time: driving time, dwell time and layover time:
- Slack time in driving time

Driving time is planned from stop to stop which facilitates the design of more accurate schedules. A small amount of slack time is added to the driving time. This amount depends on the characteristics of the track and the expected deviations. Especially tracks in the city need more slack time, because of crowded junctions and shared tracks with other traffic.

- Slack time in dwell time

It is also possible to plan some additional time per stop. This slack time depends on the expected distribution of dwell time and the effects of vehicles waiting longer than necessary at a stop. Because some tracks and stops are shared with other lines blocking of other vehicles is possible. This must be avoided, especially at high-intensity tracks. To use the additional dwell time efficiently, it is recommended to dwell longer at stops with a high number of boardings and alightenings and relatively few passengers traveling over the stop. Because of demands of the transit authority (*8)*, slack time in dwell won't be that much: the maximum dwell time is set to 20 seconds, with an exception to crowded stops where this value can be exceeded by 50%.

- Slack time in layover time

As stated earlier, additional time is added to the layover time to achieve a high punctuality of departing vehicles.

3.3 Step C: Adjusting

Deviations may still occur even after steps A and B are completed. In that case, the final step, adjusting, is performed. In (*13,14)* several operational measures are described. Adjusting the operations of RandstadRail will be done by the dispatchers in the central dispatch room. They have a total overview of all vehicles and their punctuality (*1*). Software tools are available to adjust operations and inform drivers as well as travelers.

The first goal is to guard punctuality. Dispatchers are warned by the system, when punctuality is about to exceed certain thresholds, because of, for instance:

- Vehicles that are broken down;
- Late drivers;
- Early departures;
- Late departures.

Different measures are applied, such as:

- Shortening a trip;
- Adding a vehicle;
- Skipping stops to catch up;
- Change order of vehicles (of different lines) at junctions;

These measures are always a trade-off between the travel time of travelers in the vehicle and travelers at the stops.

The secondary goal is to achieve regularity: If it is not possible to restore schedule adherence (e.g. because disturbances are too large) the dispatcher can apply regularity control. This principle is explained in (*1*). By slowing down some vehicles before and after the delayed vehicle, deviation of scheduled headways decreases and regularity will be improved. This decreases waiting times and enables a better distribution of passengers over successive vehicles. In (*15*) an application of this headway control is shown as well.

4. ACTUAL EFFECTS OF CONTROLLING

The previous paragraph describes the control philosophy, which is applied at RandstadRail to achieve a high level of reliability. RandstadRail has been in operation since 2007. Not all measures mentioned above were implemented from the start, but they are now. The level of service is still improving. This paragraph shows the actual quality of RandstadRail in terms of reliability. This shows the real impact of all measures of the control philosophy. Due to technical improvements and increased experience, the level of service will significantly increase during 2008. In early 2009, the planned high level of service of RandstadRail (comparable to level A-B with respect to the Transit Capacity and Quality of Service Manual (*16*)) can be achieved.

4.1 Schedule adherence

According to the control philosophy, the departure at the first stop is very important. RandstadRail drivers are not permitted to drive ahead of schedule. They have a display in their cabin that provides real-time information about their punctuality to adjust their on-time performance. RandstadRail confirms an improvement of departure punctuality. The percentage of trips departing with a deviation between –1 and +1 minute increased from 70% to 95%.

RandstadRail does not permit driving ahead of schedule. Driving times are planned shorter than they used to be and the cabin display helps drivers to adjust their performance. The number of trips departing ahead of schedule decreased from 50% to 5%, after the introduction of this new rule.

4.2 Variability in driving time

Two main sources for variability in driving time are: dwelling at a stop and unplanned stops (e.g. at traffic lights). Research (*10*) shows that the distribution in these elements leads to a wide distribution in driving times. It is necessary though to reduce all deviations to achieve a narrower distribution of total driving time.

4.2.1 Infrastructure improvements

To achieve a high quality of service, stopping at locations other than the stops must be avoided as much as possible. Infrastructure is reconstructed for RandstadRail: own right of way and priority at intersections is applied. Table 2 shows the average total delay per trip before and after the introduction of RandstadRail on the same route. The average value of delay has decreased and the standard deviation is also smaller, enabling a higher level of reliability.

4.2.2 Vehicle improvements

The main advantage of the new RandstadRail vehicle is the low-level floor. Boarding and alighting is much easier, especially for the elderly and people with trolleys and suitcases. Figure 5 shows the standard deviation of the dwell time of all stops in the city before and after the transformation to RandstadRail.

For most stops the standard deviation decreased. Table 3 shows that the standard deviation is reduced from 20 to 7s. The average dwell time is improved from 28 to 24 s. per stop. This enables more reliable operations with a higher level of service.

4.3 Total effect of control philosophy

The goal of the control philosophy is to improve the level of reliability by decreasing the distribution in driving times and improving the punctuality. Figure 2 shows the 15^{th} and 85^{th} value of driving times of tram line 6 before and after the application. As predicted, the distribution of deviation is decreased. In addition, punctuality is improved: the deviation is decreased and negative delays are almost disappeared.

5. CONCLUSIONS

RandstadRail is a new public transport line that replaces and connects two tram lines and a former heavy rail line. RandstadRail is a high-frequency system sharing its track with trams and metros. To offer high-quality service in terms of punctuality and regularity, and to make efficient use of the infrastructure, it is decided to apply a new control strategy. Preventing, coping and adjusting are the main elements of the control philosophy. The punctuality of the vehicle is shown to the driver, so he can adjust his driving style. On top of that, all vehicles with positions and punctuality are shown in the central dispatch room. The dispatchers use a system, supporting them in adjusting operations, if necessary. RandstadRail has a high percentage of exclusive right of way and priority at traffic lights. The vehicles got low floors and broad doors, which reduces deviations in dwell time.

The effect of all these measures is analyzed after the start of RandstadRail. It is shown that due to the control philosophy, the variability of driving times is decreased and schedule adherence is improved. Due to higher schedule adherence, mean travel times of passengers are reduced. An increase of punctuality and regularity decreased overcrowding and uncertainty.

It is to be expected that this increase of level of service will continue due to technical improvements and growing experiences.

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TABLE 1 Effect of Measures on Punctuality and Additional Waiting Time on Tram Line 6

Scenario	**Punctuality [min]**	**Additional waiting time per passenger [s]**
No measures	1.9	80
Departing on time at first stop	1.6	60
Departing on time at first stop and no early departures at all stops	1.4	50

TABLE 2 Average Stopping Time Tram and RandstadRail

	Average total delays	Standard deviation
Tram	90 s.	60 s.
RandstadRail	20 s.	30 s.

TABLE 3 Average Dwell Time Tram and RandstadRail

	Average dwell time	**Average standard deviation**
Tram	28 s.	20 s.
RandstadRail	24 s.	7 s.

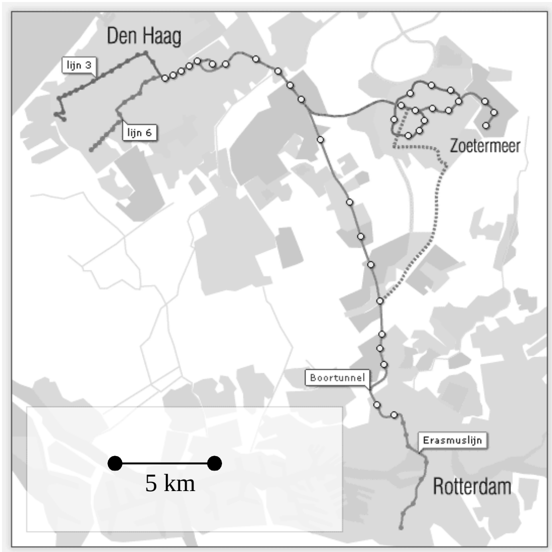

FIGURE 1 RandstadRail Network

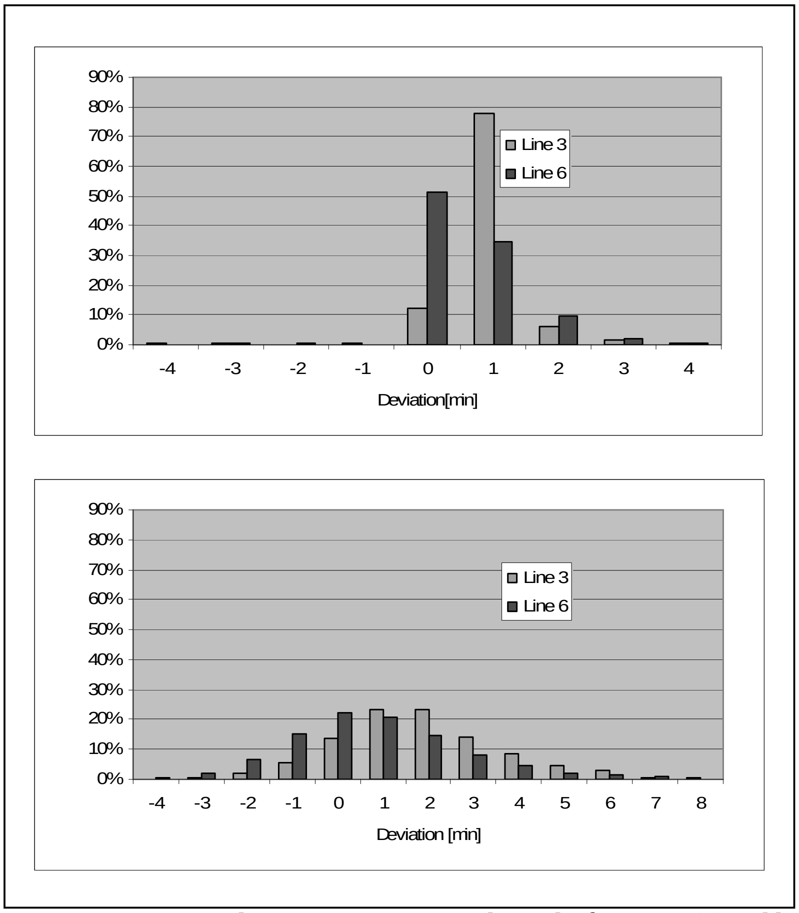

FIGURE 2 Punctuality on Tram Line 3 and 6 at the first Stop (u) and halfway the Route (l)

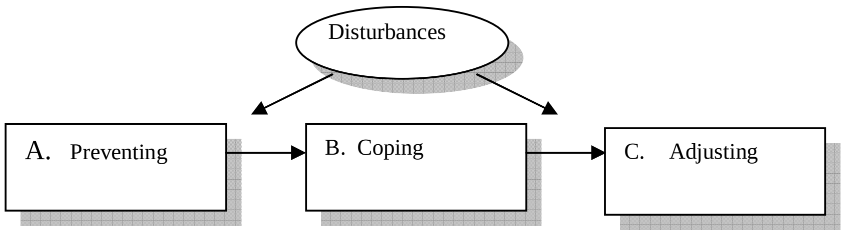

FIGURE 3 Control Philosophy

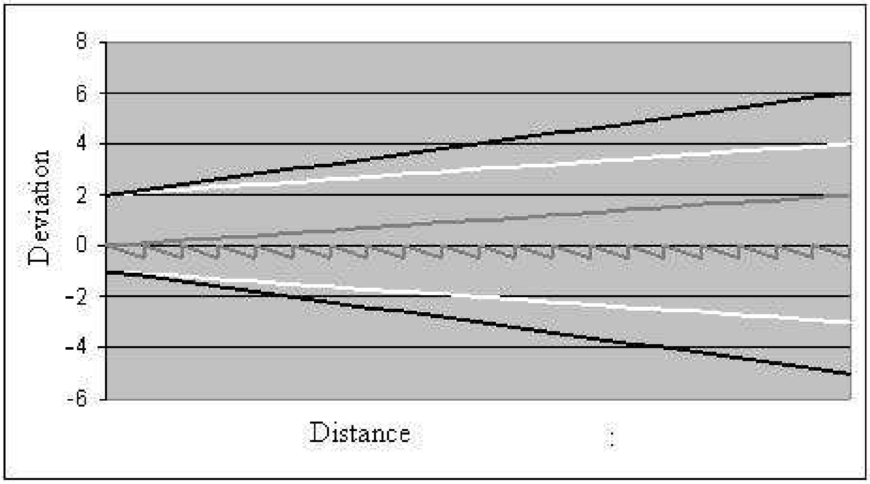

FIGURE 4 Distribution of Driving Time during the Trip (black=current; white= after improving Infrastructure and Vehicles; grey=after Improvement of Departing at first Stop and no more early Departures)

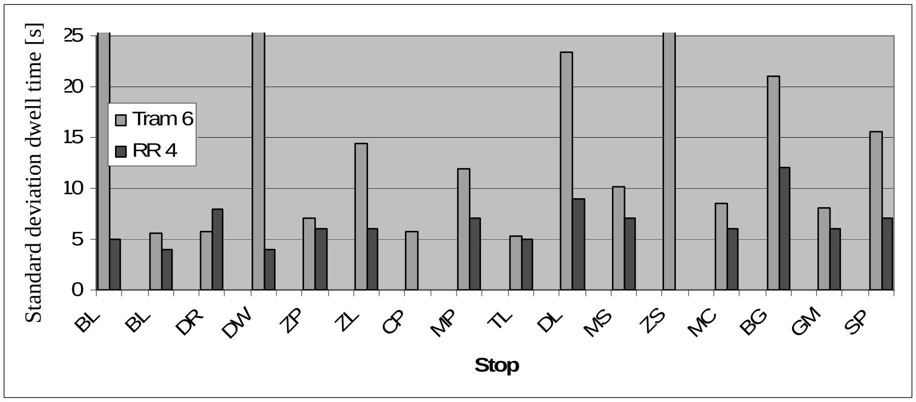

FIGURE 5 Standard Deviations of Dwell Times per Stop before and after the introduction of RandstadRail

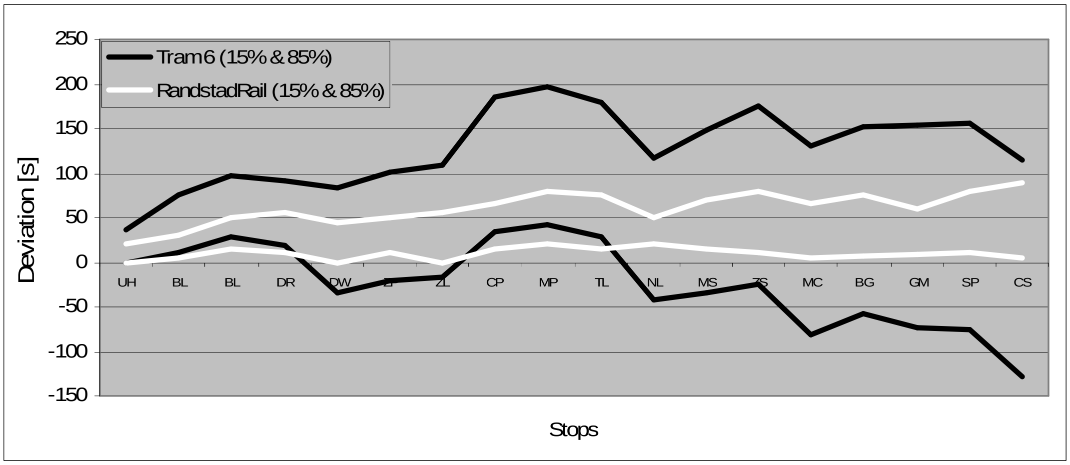

FIGURE 6 Schedule Deviation Tram and RandstadRail (15- and 85- Percentile Values)