

## **Effect of driving-time determination and holding points on reliability**

N. van Oort, M.Sc.  
HTM Urban Public Transport / Delft University of Technology  
E-mail: [N.van.Oort@HTM.net](mailto:N.van.Oort@HTM.net)

Ms. J.W. Boterman  
HTM Urban Public Transport  
E-mail: [J.Boterman@HTM.net](mailto:J.Boterman@HTM.net)

Dr. R. van Nes  
Delft University of Technology  
E-mail: [R.vanNes@tudelft.nl](mailto:R.vanNes@tudelft.nl)

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### **ABSTRACT**

This paper presents research on optimizing reliability of urban public transport. A theoretical approach and a case study show the effect of design choices of timetabling on reliability. Analysis of actual data shows that the total travel time is minimized if the 35-percentile value is used to determine the driving time out of historical data. This saves up to 75% of additional travel time due to unreliability for all passengers.

If holding points are applied (and departing ahead of schedule is not allowed), the travel time can be even more reduced. A theoretical and a practical study show that designing 2 holding points, using a 30-60 percentile value minimizes travel time (reduction of additional travel time up to 60%), regarding both the waiting time at the stops and in the vehicle.

## 1. INTRODUCTION

The quality of public transport is determined by many aspects, such as availability, comfort, travel time and costs. Reliability of travel time has become increasingly important over the last decade. Deviations of the timetable result in additional travel time and reduce the probability of finding a seat (Van Oort and Van Nes 2008). Reliability strongly influences mode choice, as stated in Van Oort and Van Nes (2004). In urban public transport, reliability is not optimal. A case study in The Hague in The Netherlands shows the effects of unreliability on travel time of passengers. The analysis of actual data of buses and trams shows that travel time can be extended by 25% due to distribution in travel times. Van Oort and Van Nes (2008) state that the focus of research and applications of improvements in reliability is often on the operational level: the network and timetable are given and the only way to improve reliability is by adjusting operations such that they are better aligned with the timetable (e.g. as shown in Chang et al (2003), Chowdhury and Chien (2001), Furth and Muller (2006), Muller and Furth (2000) and Wilson et al (1992)). Figure 1 illustrates how reliability is defined: the match of planning and operations.

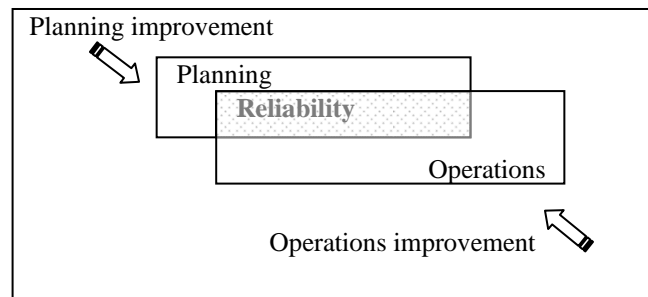


Figure 1: (Improving) reliability

To achieve the highest level of reliability, planning and operations should be equal. Improving reliability is thus a matter of adjusting one of these aspects to the other. The hypothesis in Van Oort and Van Nes (2008) is that by both adjusting operations and planning, opportunities are created to improve the match. This paper describes research on improving reliability of urban public transport by optimizing timetables, theoretically as well as by conducting a case study in the city of The Hague. Variation of operations are known and the timetable is adjusted to create an optimal match, achieving minimal travel time for passengers. Figure 2 shows the elements of the travel time.

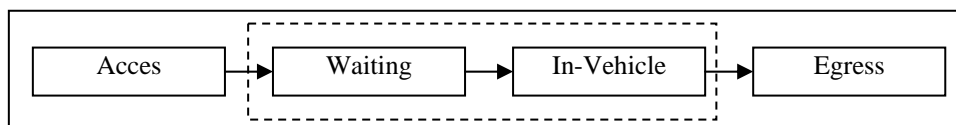


Figure 2: Elements of travel time and research focus

This research focuses on the part of the journey from the arrival of the passenger at the origin stop until the arrival of the passenger at the destination stop. Transfers are not included. This part of the journey consists of waiting time at the origin stop and the time spent in the vehicle. The waiting time depends on the scheduled and actual departure of the vehicle: this schedule adherence determines the amount of time the passenger has to wait additionally compared to the situation where all vehicles operate perfectly on time. In-vehicle time is assumed to be constant. If a holding strategy is applied, the waiting time of vehicles due to holding is also taken into account. The analysis in this paper only considers periods of the day, where passengers arrive at the origin stop according to the departure times. A customer survey

conducted by HTM shows that people tend to arrive about 2 minutes before the scheduled departure, if frequencies are 6 vehicles/hour per direction or lower.

The paper is organised as follows: paragraph 2 explains the design process of timetable and the main variables: the driving time. The application of holding points is also explained. A calculation model is described in paragraph 3, enabling calculation of the additional travel time as a function of choices in the timetable design process. A theoretical analysis is made of a fictive line as well as a case study, using actual data of driving time and passenger flow in the city of The Hague. The results of both analyses are shown in paragraph 4. The paper ends with conclusions and a reference citation.

## 2. TIMETABLE DESIGN

This paper focuses on the tactical stage of urban public transport design: during this phase, the timetable is constructed. A variety of factors are important in designing a proper timetable. Given a public transport network, frequency should be determined: how many departure possibilities are provided per hour? This relates to both quality and capacity; how many seats are offered per hour, and is a sufficient level of comfort achieved? Coordination with other lines is important as well during the timetable design: this applies to both transfer options and to offering a constant interval on a track with more than 1 line. Through this coordination, the departure times in the timetable are fixed exactly on time.

### 2.1 Driving time

The main element of a timetable, besides the number of runs, is the driving time, i.e. the time necessary to drive from stop to stop. In urban public transport, contrary to heavy rail, it is common practice to determine the driving time based on empirical data for the previous period. Using this type of feedback, attainable driving times are scheduled. An example of empirical data of driving times is illustrated in figure 3: the realized driving times of tram line 1 (Scheveningen-Delft, working days, morning peak, April 2007) are shown.

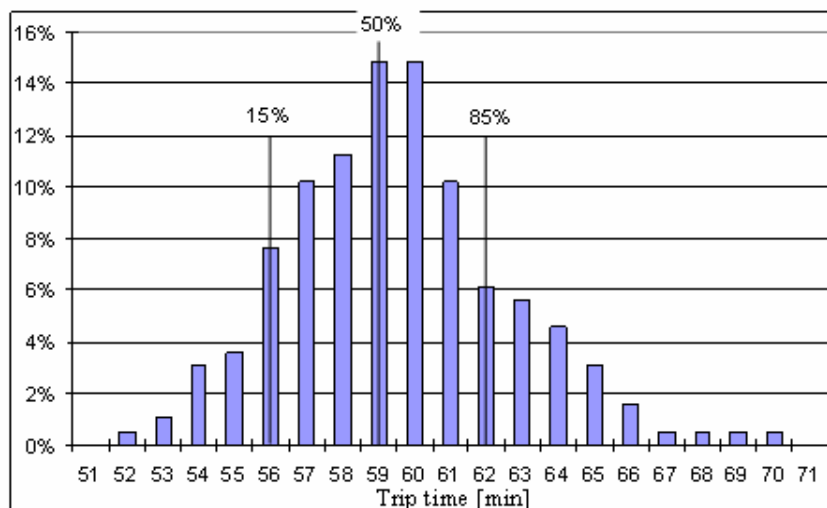


Figure 3: Distribution of driving times for tram line 1 and percentile values

Figure 3 shows that the realized driving times have a distribution which is caused by several factors, such as weather, traffic, variation in the number of passengers, human interaction, etc. Cham and Wilson (2006) provide a detailed description of possible sources. The challenge for the planner is to choose the best driving time out of this distribution, since only one time can be used as input for the timetable. By choosing a single driving time, knowing the real driving

times are distributed, schedule adherence will not become optimal: without further measures, differences will arise between the timetable and actual operations.

The driving time is normally chosen by selecting a percentile value. Figure 3 indicates the 15-, 50- and 85-percentile values. It is common use in urban public transport to select a high percentile value, achieving a high level of attainability.

Muller and Knoppers presented research, recommending the 85-percentile value, which leads to an attainable timetable.

## 2.2 Holding points

Holding points are stops where drivers are not allowed to leave ahead of schedule. Introducing holding points will affect reliability and travel time. Not driving before the scheduled time reduces the variety in driving times, as figure 4 shows. At holding point  $p$ , vehicles that have arrived early wait until they are on time. This decreases the distribution of the deviation. Holding points are used, for example, at RandstadRail (light rail service in The Hague), as described by Van Oort and Van Nes (2007). This paper presents the results of a research study on designing driving time and holding points: how many points should be introduced and what percentile value should be used for the driving towards the holding point to minimize additional travel time.

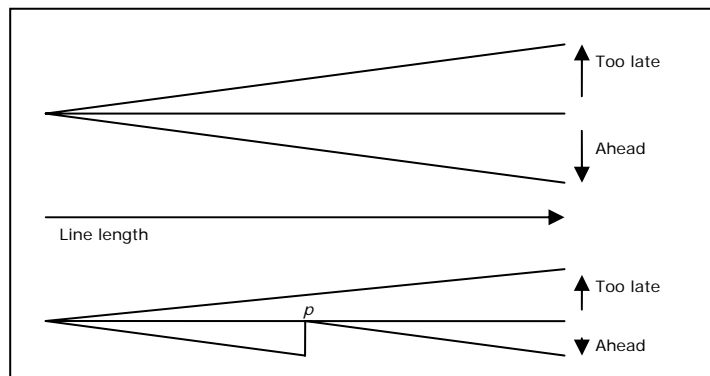


Figure 4: *Effect of holding point  $p$  on schedule adherence*

Not every stop is useable as a holding point. At a good holding point, the proportion of travellers who board and alight is high. People who travel from a stop before the holding point to a stop after, gain no advantage from waiting at the holding point. In the same way as used in driving time determination, the driving time from holding point to holding point can also be chosen by a percentile value out of a distribution of realized driving times.

### 2.3 Consequences of driving time determination and holding points

The final choice of the driving times has many consequences. Divided into supply issues and demand issues, the main ones are:

#### Supply

- The probability of departing on time at the first stop  
If many vehicles are delayed, the probability of a punctual departure of the next run will decrease. This depends both on the delay and on the slack in the layover time at the terminus.
- Attainability for the driver  
The longer the driving time, the larger the probability that a driver will arrive within the scheduled time. The consequence could be that drivers are ahead of schedule.
- Number of vehicles needed  
The number of vehicles required to operate the timetable is determined by the frequency and round-trip time of the line. This time consists of driving time and layover time in two directions. If the driving time decreases, one vehicle is able to run more runs, and fewer vehicles are required. However, no fractions of vehicles can be used, so a reduction will not automatically decrease the number of vehicles. If the scheduled driving time is not attainable, the frequency will drop and/or the actual layover will decrease.

#### Demand

- Travel time of passengers  
As illustrated by figure 2, the total journey does not only consist of driving time. Waiting comprises a substantial part of the trip as well, especially in urban transport. If operations do not match the planning, the waiting time at the stop increases (Van Oort and Van Nes, 2008). If vehicles drive ahead of schedule, it is possible that passengers miss their vehicle and have to wait a complete headway. The choice of what percentile value of the previous data is used for a new timetable determines the punctuality and therefore waiting time and travel time.

The choice of the optimal percentile value is a major topic in many public transport companies. The effects mentioned above show the large consequences of the choice of driving time. This paper describes a quantitative analysis of the choice of percentile value and application of holding points. Two effects are shown: the additional travel time caused by the mismatch of planning and operation and the probability of departing on time at the first stop for the next run. In analyzing the effect of driving times, the following aspects are of primary interest:

- The distribution of driving times: the larger the bandwidth, the larger the effect on punctuality and probability to arrive at the last stop on time.
- Frequency: The smaller the frequency, the larger the effect of driving ahead of schedule. After all, people have to wait a complete headway if they miss the vehicle.
- Number of boardings. The stops where people board and their location at the line are of great importance. Once passengers have boarded and are on their way, the departure time at the following stops are no longer relevant.
- Layover time: The time at the last stop, before departing in the other direction can be used as slack time to make up for delays. A portion of this time can also be used as a break for the drivers. This portion is not taken into account in this research.

Actual driving times are assumed to be fixed in this research; only the scheduled driving time is changed. This scheduled time is communicated to passengers and they adjust their moment of arrival at the departure stop, which determines their waiting time. In another scenario, an analysis is made of whether vehicles are not allowed to depart ahead of schedule: the introduction of holding points. As mentioned earlier, the effects of driving ahead of schedule are considerable, i.e. an extension of waiting time by a complete headway. In this case, the number of passengers in the vehicle is used as additional input. . Due to the fact that vehicles are not allowed to depart early, these passengers could have to wait at the stop. This leads to additional travel time for the passing passengers.

### 3. CALCULATION MODEL

A model is designed to analyze the effect of the choice of driving time and holding points on punctuality, travel time and the probability of on-time departure. This paragraph describes this model and the algorithms used, as well as specifying the data used.

#### 3.1 Calculation of punctuality and additional travel time

The first step in the model is constructing the timetable. The main variable is the percentile value, which is used to determine the scheduled driving time based on the data of actual driving times during the previous period. After the percentile value is chosen, the complete timetable is determined. The main input is, of course, actual data from the operations, i.e. driving times from stop to stop on a certain line. The next step is to compare the newly constructed timetable with the stochastic set of driving times. This is under the assumption that driving times are not affected by the timetable. Now the deviation of the timetable can be calculated, using formula 1.

$$\bar{p} = \frac{\sum_{j=1}^{n_j} \sum_{i=1}^{n_i} |t_{i,j}^{real} - t_{i,j}^{scheduled}|}{n_i * n_j} \quad (1)$$

Where:

$\bar{p}$	= average punctuality on the line
$t_{i,j}^{real}$	= real departure time of vehicle $i$ on stop $j$
$t_{i,j}^{scheduled}$	= scheduled departure time of vehicle $i$ on stop $j$
$n_i$	= number of journeys
$n_j$	= number of stops
$i$	= journey number
$j$	= stop number

Punctuality is a commonly used indicator for reliability, but does not take into account the difference between the effect of driving ahead of schedule or driving late. To consider this, a model is developed that computes the additional waiting time per traveller due to variety of driving times (see formula 2-3). A passenger survey (HTM 2008) showed that passengers do

not experience any additional waiting time when the actual departure is between 2 minutes before and 1 minute after the scheduled departure. Driving ahead leads to a waiting time equal to the headway. Particularly in the case of low frequencies, this means a large increase in waiting time. Driving late creates additional waiting time equal to the delay. The additional waiting time is first calculated per stop and afterwards it is computed as a weighted average for all passengers on the line, depending on the number of boardings per stops (first part of formula 6). When holding points are used, waiting time in the vehicle must be considered as well. Formulas 4-6 show the computation of that, including the calculation of the average effect for all passengers.

In the end, all waiting times per stop are added, taking into account the number of passengers at a stop and the number of passenger incurring additional travel time in the vehicle at the holding point. This results in the average additional travel time for all passengers on the line.

$$\begin{cases} ET_{i,j}^{stop} = H, & p_{i,j} \leq -120 \\ ET_{i,j}^{stop} = 0, & -120 < p_{i,j} < 60 \\ ET_{i,j}^{stop} = p_{i,j}, & p_{i,j} \geq 60 \end{cases} \quad (2)$$

$$ET_j^{stop} = \frac{\sum_{i=1}^{n_i} ET_{i,j}^{stop}}{n_i} \quad (3)$$

$$\begin{cases} ET_{i,j}^{veh} = |p_{i,j}|, & \text{stop } j \text{ is holding point and } p_{i,j} < 0 \\ ET_{i,j}^{veh} = 0, & \text{stop } j \text{ is holding point and } p_{i,j} \geq 0 \\ ET_{i,j}^{veh} = 0, & \text{stop } j \text{ is no holding point} \end{cases} \quad (4)$$

$$ET_j^{veh} = \frac{\sum_{i=1}^{n_i} ET_{i,j}^{veh}}{n_i} \quad (5)$$

$$ET^{TOTAL} = \sum_{j=1}^{n_j} \alpha_j * ET_j^{stop} + \beta_j * ET_j^{veh} \quad (6)$$

Where:

$ET_{i,j}^{stop}$  = additional waiting time due to vehicle  $i$  at stop  $j$

$H$  = scheduled headway

$p_{i,j}$  = deviation of vehicle  $i$  at stop  $j$

$ET_{i,j}^{veh}$  = additional waiting time in vehicle  $i$  at stop  $j$

$ET^{TOTAL}$  = average additional waiting time per passenger

$\alpha_j$  = proportion of passengers boarding at stop  $j$

$\beta_j$  = proportion of passengers passing stop  $j$

### 3.2 Calculation of probability of departing on time

Besides the additional travel time, the probability of on-time departure at the first stop is calculated by the model as well. The model calculates the punctuality deviation at the last stop for every journey and uses this value in combination with the layover time to determine the departure delay (if the arrival delay is greater than the layover time; otherwise, no delay will occur). After the departure delay for all trips has been calculated, the probability of on-time departure is determined.

## 4 RESULTS

Below the results are shown of the study on minimizing additional travel time by adjusting the timetable. Both a theoretical analysis and a case study are conducted. The input for the theoretical analysis is a fictive line with a driving time of 30 minutes, serving 30 stops. The boardings and alightings are distributed across the line, as figure 5 shows.

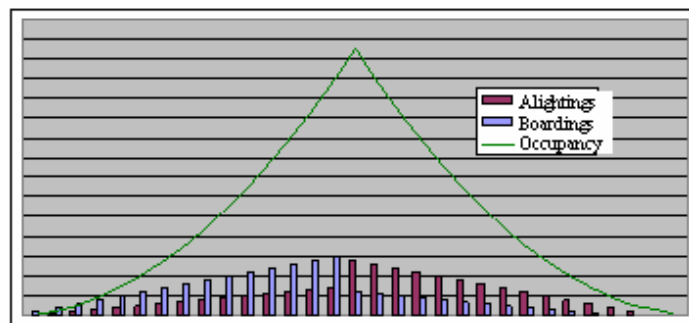


Figure 5: Distribution of boarding and alighting theoretical line

The driving times are assumed to be Gaussian distributed. Three scenarios are analyzed: driving times with 5%, 10% and 20% of the driving time as standard deviation.

The case study consists of different tram and bus lines (in terms of length and distribution of driving times) operated by HTM in The Hague. Actual driving times and passenger flows are used as input. Table 1 shows the main characteristics of the lines analyzed.

Table 1: Characteristics tram lines case study

Line	From	To	Length [km]	Driving time [min]	Standard deviation [min]	Relative Standard deviation <sup>3</sup>	Schedule
1 <sup>1&amp;2</sup>	Scheveningen	Delft	20.0	60	3	5%	Tight
2 <sup>2</sup>	Kraayenstein	Leidschendam	13.0	43	3	6%	Wide
9 <sup>1</sup>	Vrederust	Scheveningen	13.7	40	4	10%	Normal
11 <sup>1</sup>	Scheveningen	Den Haag HS	8.1	22	2	9%	Normal
15 <sup>2</sup>	Moerwijk	Nootdorp	16.7	52	3	7%	Tight
17 <sup>1</sup>	Statenkwartier	Wateringen	16.4	42	3	7%	Normal
18 <sup>2</sup>	Clingendael	Rijswijk	14.5	49	7	15%	Wide

<sup>1</sup> Working days, April 2007

<sup>2</sup> Working days, February and March 2007

<sup>3</sup> Percentage of driving time

The actual data of these lines is gathered by the TriTapt monitoring tool (Muller and Knoppers (2005), which is used by HTM to monitor and analyze the operations of all tram and bus lines. The period used is February - April 2007. All trips are operated on working days from 6 p.m. to 8 p.m., offering headways of 15 minutes.

#### 4.1 Driving time determination

The next paragraph shows the results of a theoretical study and a case study on the effect of driving time determination on additional driving time. The effect on the probability of on-time departure at the first stop is also analyzed.

##### 4.1.1 Theoretical analysis

The results of the theoretical case are shown in figure 6. For three different driving times, the additional travel time per passenger is shown as a function of chosen percentile value. This figure illustrates that the average additional travel time increases if the distribution of driving times increases and if the percentile value increases.

The minimum additional travel times is achieved if a 35 percentile (or lower) value is chosen. Depending on the standard deviation of the driving time is the value of additional driving time between 0.5 and 4 minutes. The difference between the 85 and 35 percentile value lies between 0.5 and 11 minutes.

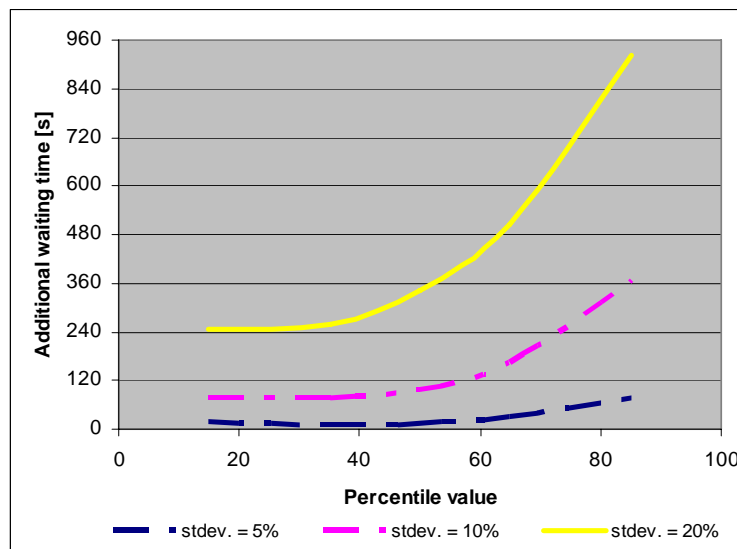


Figure 6: Additional travel time as function of percentile value theoretical line (driving time 30 min, standard deviation 5, 10 and 20%)

Figure 7 shows the effect of the chosen percentile value on the probability of on-time departure at the first stop, using a theoretical line of 30 minutes, regarding a 10% standard deviation. Both an increasing layover time and percentile value lead to a higher probability. To ensure a punctual departure, a layover time between 15% and 35% of the driving time is necessary.

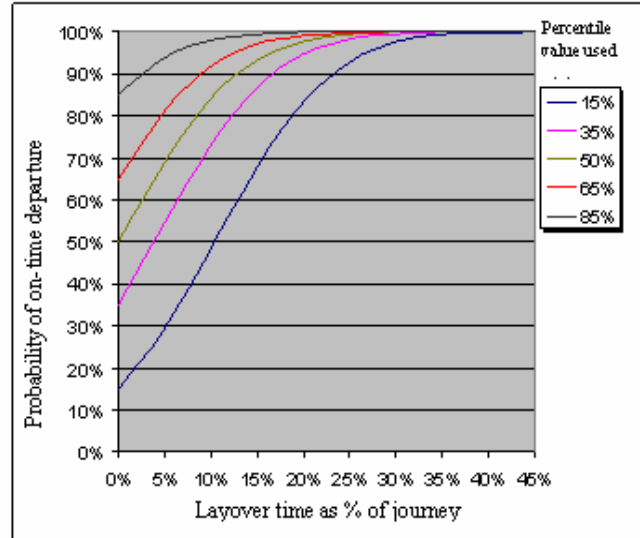


Figure 7: Probability of on-time departure as a function of percentile value and layover time

If the percentile value decreases, more layover time is needed to ensure punctual departures in the opposite direction. Nevertheless, this additional time is saved in the driving time, using a lower percentile value. In fact, this is a redistribution of time between driving and layover time, not adjusting total round trip time at all.

#### 4.1.2 Case study: tram lines in the Hague

In addition to a theoretical approach, a case study is conducted in order to assess the impact of the percentile value choice.

Figure 8 shows the additional travel time for passengers as a function of the chosen percentile value for 4 tram lines. This figure shows a large increase in additional travel time if the percentile value exceeds 50. The minimum value, 0.5-1.5 minutes, is reached when the 35 percentile value is used. This matches the theoretical analysis. Also shown is a large difference depending on the chosen percentile value. On average, passengers will experience 2 to 5 minutes additional travel time if the 85 percentile value is used, instead of the 35 percentile.

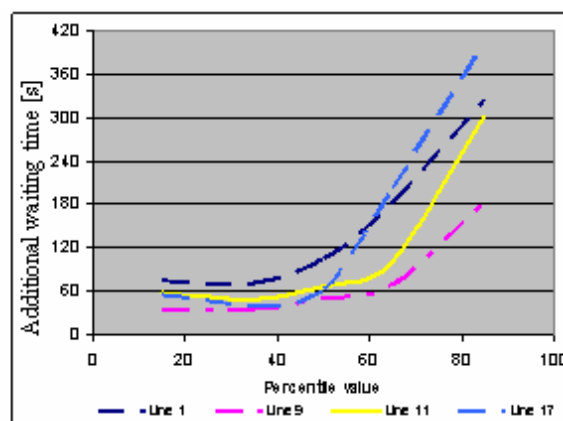


Figure 8: Additional travel time as a function of percentile value

Figure 9 shows the probability of on-time departure from the first stop of tram line 11 as a function of percentile value and layover time. The characteristics of this line are shown in table 1. The results match those of the theoretical analysis. This also confirms that a redistribution of total journey time is necessary: reducing the run time and increasing the

layover time. This ensures that passenger travel time is minimized and departure punctuality for the first stop of the next run is not affected.

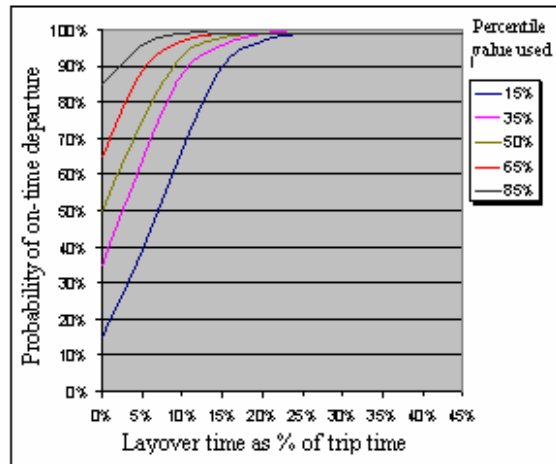


Figure 9: Probability of on-time departure as a function of percentile value and layover time tram line 11

#### 4.2 Holding points

This study also examined the effect of introducing holding points. In this case, the additional travel time consists of two parts: time at the stop and time spent in the vehicle. Figure 10 shows that when using higher percentile values, the additional waiting time shifts from travellers at the stop to travellers in the vehicle. The following paragraphs show the effects of the number and location of holding points and the percentile value, which is chosen to set the departure time at the holding point.

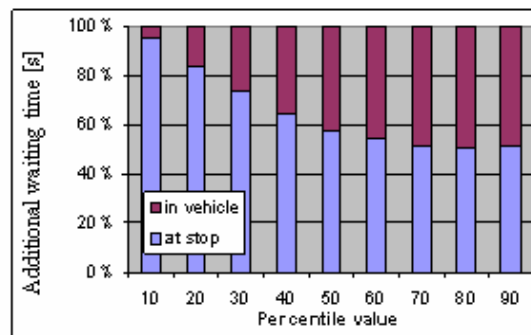


Figure 10: Additional travel time tramline 1 with four holding points divided into two parts: in the vehicle and at the stop

##### 4.2.1 Theoretical analysis

Figure 11 (on the left) shows the effect of the number of holding points on a theoretical line with a standard deviation of 4 minutes. It appears that introducing more than two points does not significantly reduce additional travel time. However, when more holding points are used, the reduction of additional travel time will be distributed among more passengers. The optimal percentile value lies between 30 and 50%. Figure 11 (on the right) also shows the effect of the chosen percentile value with which the driving time to the holding point is designed. Besides the number of holding points, this value depends on the standard deviation of the driving time: the higher this deviation, the higher the optimal value of the percentile value. Research of data of real lines supports these conclusions.

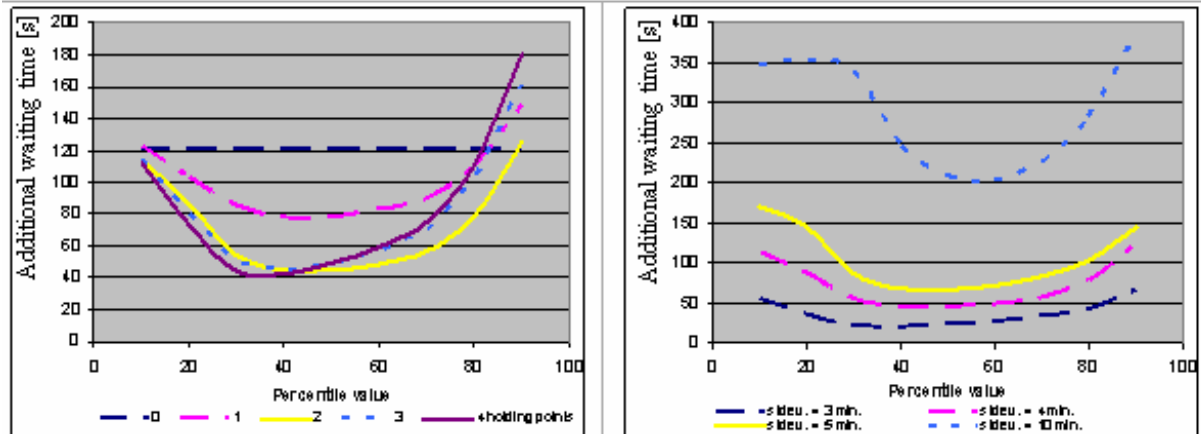


Figure 11: Additional travel time theoretical line (st. dev.=4 min) as a function of percentile value and number of holding points (l) and additional travel time theoretical line (2 holding points) as a function of percentile value and st.dev. of driving time(r)

#### 4.2.2 Case study: tram lines in The Hague

Figure 12 shows the additional travel time by applying two holding points on three tram lines and one bus line. Lines 2 and 15 had excessive driving time (see also table 1) and a small distribution of realized driving times. The optimal percentile value is high (60-80-percentile). For tramline 1 the driving time was too short and the realized driving times had a relatively low standard deviation. The optimum is about 20%. Like tramline 1, on bus line 18 the timetable driving time was short but realized driving times are widely distributed. The optimal percentile value is about 40%.

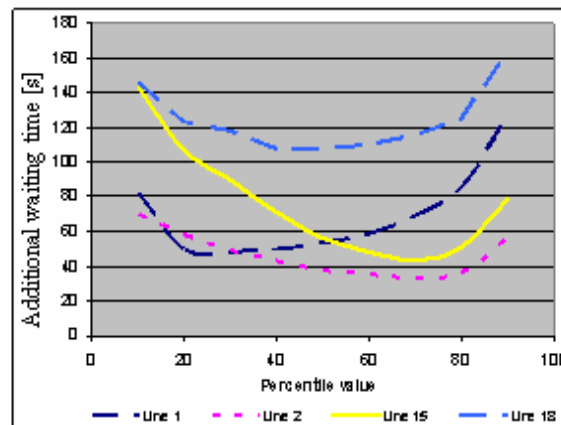


Figure 12: Additional travel time as a function of percentile value(2 holding points)

#### 4.2.3 Location choice of holding points

As noted above, it is important to choose a good location for a holding point. Figure 13 shows the additional travel time by scheduling a holding point at the beginning, middle and end of the tram line 1. In general, a holding point at the beginning of a line is desirable (there will still be many boardings ahead) but not yet necessary (the line is not yet greatly deviated). A holding point at the end of a line is necessary because of the higher standard deviation, although only few travellers will benefit. The best location for a holding point thus depends

on the distribution of travellers on a line. The case of line 1 shows that a holding point at the beginning of that line (at  $\frac{1}{4}$  of the length) is the optimal location.

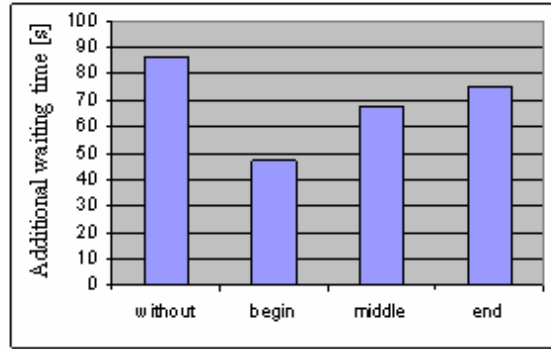


Figure 13: Additional travel time by using one holding point at the beginning, middle and end of tram line 1

#### 4.3 Driving time determination and holding point at high frequent lines

This research is based on the assumption that people tend to arrive at the departure stop depending on the departure time. It is shown that additional travel time decreases when using lower percentile values during the design of driving times. Also, using holding points helps to reduce additional travel time. But also when passengers arrive at a stop at random, additional travel time can be reduced by using low percentile values and holding points. Boterman (2008) showed the relation of regularity and punctuality, shown in formula 7.

$$PRDM_{i,j} = \left| \frac{P_{i+1,j} - P_{i,j}}{TIT_{i,j}} \right| \quad (7)$$

Where:

$PRDM_{i,j}$  = relative irregularity of vehicle  $i$  on stop  $j$

$TIT_{i,j}$  = planned headway of vehicle  $i$  on stop  $j$

It shows that the irregularity on a line depends on the punctuality of vehicle  $i$  and vehicle  $i+1$ . Because low percentile values and the use of holding points prevent vehicles from driving ahead of schedule,  $p_{i+1,j}$  and  $p_{i,j}$  are both positive values. Compared to the situation that  $p_{i+1,j}$  and  $p_{i,j}$  could be both positive and negative numbers, the maximum value of  $|p_{i+1,j} - p_{i,j}|$  decreases: the irregularity will thus decrease.

## 5. CONCLUSIONS

This paper presented research on optimizing the reliability of urban public transport. Ways of improving reliability by adjusting the timetable are analysed. A theoretical approach and a case study show the effect of design choices of timetabling on reliability. Analysis of actual data shows that the total travel time of passengers is minimized if the 35-percentile value is used to determine the driving time based on historical data. This saves up to 75% of the additional travel time due to unreliability for all passengers on a line.

If holding points are used (and departing ahead of schedule is not allowed), the additional travel time can be reduced even more. The optimal percentile value by using holding points depends on three variables:

- The value of the relative standard deviation. The higher the standard deviation, the higher the optimal percentile value.
- Too long or too short timetable driving times. The tighter the schedule, the lower the optimal percentile value.
- The number of holding points. The impact of two holding points on the additional travel time is greater than when only one is used, but almost equal to three or four.
- The best location for a holding point depends on the distribution of travellers on a line.

A theoretical and a practical study show that designing 2 holding points, using a 30-60 percentile value minimizes travel time (additional travel times are reduced up to 60%) in terms of both the waiting time at the stops and in the vehicle.

## ACKNOWLEDGEMENTS

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## REFERENCES

1. Boterman J.W. (2008), Travelling faster by holding vehicles, Bachelor thesis, HTM/Fontys (in Dutch).
2. Cham, L.C., Wilson, N.H.M. (2006), Understanding bus service reliability, A practical framework using AVL/APC data, Washington DC.
3. Chang J. et al.(2003), Evaluation of service reliability impacts of traffic signal priority strategies for bus transit, *Transportation Research Record no. 1841*, Washington D.C., p. 23-31.
4. Chowdhury S., Chien S. (2001), Dynamic vehicle dispatching at intermodal transfer station, *Transportation Research Board 80th annual meeting*, Washington, D.C.
5. Furth, P.G., Muller (2006), Th.H.J., Reliability-based time point and recovery schedules for long headway transit routes, *CASPT conference*, Leeds.
6. HTM Department of Research and Development (2008), Survey Customer Satisfaction, The Hague.
7. Muller Th.H.J., Furth P.G.(2000), Conditional bus priority at signalized intersections: better service with less traffic disruption, *Transportation Research Record no. 1731*, Washington D.C., p.23-30.
8. Muller, Th.H.J., Knoppers P., Modal shift: The objective of improving transit quality. The contribution of off-line trip information to planning, operational control, process management and service information, TU Delft.
9. Muller Th.H.J., P. Knoppers (2005) TRIP Time Analysis in Public Transport, [<http://tritapt.nl/>]
10. Oort N. van, R. van Nes (2009), Controlling operations of public transport to improve reliability: theory and practice, in: *88th Annual Meeting of the Transportation Research Board*, Washington D.C.
11. Oort N. van, R. van Nes (2008), Improving reliability in urban public transport in strategic and tactical design in: *87th Annual Meeting of the Transportation Research Board*, Washington D.C.
12. Oort, N. van, R. van Nes (2007), RandstadRail: Increase in public transport quality by controlling operations In: *Proceedings Second International Seminar on Railway Operations Research*, Hannover.
13. Oort N. van, R. van Nes (2006), Service Regularity Analysis for Urban Transit Network Design, *CASPT conference*, Leeds.
14. Wilson et al.(1992), Improving service on the MBTA green line through better operations control, *Transportation Research Record 1361*, TRB, National Research Council, Washington D.C., p. 296-304.