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# IMPROVING RELIABILITY IN URBAN PUBLIC TRANSPORT IN STRATEGIC AND TACTICAL DESIGN

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**ABSTRACT**

1 Reliability is one of the key level of service indicators in public transport. In urban areas several sources lead to poor  
2 schedule adherence. When reliability is poor, passengers will experience longer waiting times at stops and during  
3 transfers. Because of the relatively short journeys in urban areas, the increase of waiting times is significant. Next to  
4 the increased travel times, unreliability also results in less comfort and a smaller chance of having a seat, because of  
5 bunching of vehicles. Besides, travelers don't appreciate uncertainty during their trip. Normally, reliability issues are  
6 analyzed and improved at the operational level of public transport. The hypothesis in this research is that already  
7 during the strategic and tactical planning phases reliability can be taken into account and be improved. This paper  
8 uses a case study of the tram lines in The Hague in The Netherlands to show the effect of unreliability for  
9 passengers. An analysis of actual travel time components is made for a better understanding of the problem.  
10 Solutions during the planning phases are suggested and analyzed. It is shown that using other parameter values in  
11 timetable planning than currently applied, leads to less extra waiting time for travelers. The effect of taking  
12 reliability explicitly into account when designing line length, stop spacing and coordination strategies is analyzed as  
13 well. This research thus demonstrates that improvements in reliability can already be achieved during the planning  
14 phases of public transport.  
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## 1. INTRODUCTION

1 Reliability is one of the key level of service indicators for public transport. In urban areas several sources lead to  
2 poor schedule adherence, for instance other traffic, weather, variable number of travelers, behavior of drivers, etc.  
3 All these elements have a negative influence on driving times and dwell times, leading to deviations of the  
4 scheduled departure times at stops. These deviations affect transit companies as well as passengers. Due to the  
5 variation in system performance, additional resources are applied by transit companies while passengers will  
6 experience longer travel times, due to longer in-vehicle times, as well as increased waiting times at stops and during  
7 transfers. Because of relatively short journeys in urban areas, the extension of the waiting time is significant. Next to  
8 extension of travel time, unreliability also causes less comfort and a smaller chance of having a seat, because of  
9 bunching of vehicles. Besides, traveler's uncertainty during a trip will lead to lower customer satisfaction.

10 This paper describes a research on reliability of urban public transport. Its hypothesis is that already during  
11 the planning phases reliability can be improved. Normally, a lot of attention is paid to this problem during the  
12 operational phases (1,2 and 3). Examples of applied measures are conditional priority (giving priority only to  
13 vehicles, which are ahead of schedule) and dispatching by a central post or by employees at main stops. It is unclear,  
14 however, how strategic and tactical design of public transport systems affect the service reliability. Since it might be  
15 expected that measures aiming at improving reliability at these planning levels will make it easier to provide high  
16 quality services at the operational level, this hypothesis deserves further study.

17 This paper presents an analysis of the actual performance of the public transport system in the Dutch city of  
18 The Hague operated by the "HTM Personenvervoer" company. The results of this quantitative analysis are used to  
19 derive strategic and tactical design options that might improve urban public transport service reliability, being a first  
20 step towards a more integral approach to improve public transport reliability.

21 This paper starts with a description of the effects of reliability. In the next section outcomes of the case  
22 study on the current reliability of the public transport in The Hague will be presented. After that the possibilities for  
23 improving reliability will be described, with special attention to measures that relate to strategic and tactical  
24 planning. This paper ends with conclusions and recommendations for further research.  
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## 2. EFFECTS OF SERVICE RELIABILITY ON USER BEHAVIOR AND SATISFACTION

1 One of the key quality indicators of public transport is service reliability. Variations in the system's performance,  
2 and thus the system's reliability, affect travelers in several ways. Their travel times will vary and will usually  
3 become longer. The probability of finding a seat will decrease. Overall the appreciation of traveling by public  
4 transport will decrease, leading to a lower patronage. In the remainder of this section these aspects will be discussed  
5 in more detail.

6 Travel time is an important characteristic for travelers choosing the mode and route they want to use to  
7 make a journey. Travel time consists of the following components:

- 8 • Access time
- 9 • Waiting time
- 10 • In vehicle time
- 11 • Transfer time (optional)
- 12 • Egress time

13 Variability of travel time in public transport mostly affects waiting time. Waiting time, both at the first stop  
14 and at an interchange station increases because of unreliability. If the arrival pattern of passengers is based on the  
15 schedule, waiting times will be extended by the delay of the vehicle. If the vehicle is ahead of schedule, travelers  
16 even have to wait for the full headway. In case of low frequencies this results in substantial extra waiting times.

17 If travelers arrive at random at the stop, the headways of successive vehicles should be constant. In that  
18 case the average waiting time is minimal. Increased irregularity again causes an increase in waiting time. If the  
19 irregularity is 100%, i.e. vehicles operate in pairs, the average waiting time will be doubled.

20 The fact that unreliability increases waiting times is even more important as travelers perceive waiting time  
21 to be more unattractive than in-vehicle time. Research (4) shows the appreciation of different components of travel  
22 time: one minute waiting is perceived the same by travelers as 1.5 minutes in-vehicle time.

23 Unreliable operations also lead to less comfort. Because of delays more travelers will be waiting at the next  
24 stop. As a result the boarding and alighting process will take more time, which will enlarge delay as well. At the  
25 next stop even more extra passengers will be waiting. This phenomenon will create bunching of vehicles and a poor  
26 distribution of passengers over the vehicles. Most travelers will enter an overcrowded vehicle; some will enter an  
27 almost empty one.

28 Variability also affects travelers' satisfaction. HTM regularly monitors the customer satisfaction (5). One of  
29 the aspects included in the survey is reliability. 15% to 20% of the travelers are not satisfied with the quality of  
30 reliability. As a reference: 95% of the travelers are satisfied with the services provided by HTM. Improving  
31 reliability thus increases customer satisfaction.

32 Finally, reliability of service affects rider ship, since travelers do not like uncertainty during their trip.  
33 Research (6) shows that people are likely to change their mode of transport because of changes in reliability. This  
34 research shows that variability in travel times has a great impact on the mode choice of travelers. Especially  
35 occasional travelers seem to be very sensitive to changes in reliability. So, improving service reliability will increase  
36 rider ship too.

### 3. CASE STUDY: PUBLIC TRANSPORT SERVICE UNRELIABILITY IN THE HAGUE

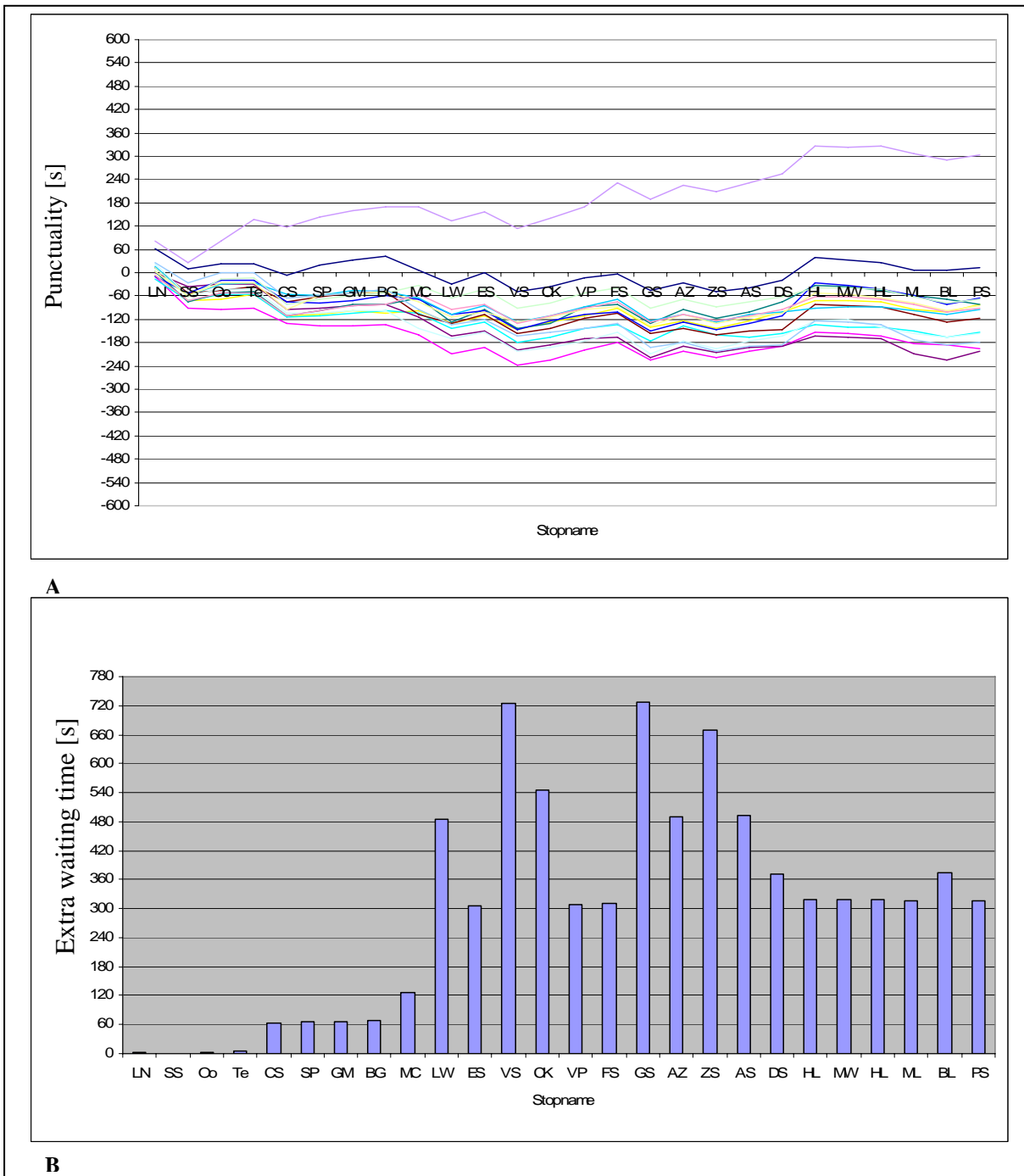
To learn about actual service variability and its effects, observations were performed. This case study is based on the public transport network of The Hague in The Netherlands (7). The public transport company of this city, HTM, operates 11 tram and 10 bus lines with a total length of 550 km.

Two cases are considered: Low frequencies (up to 4 vehicles per hour) implying that travelers adapt their arrival pattern to the schedule and high frequencies (more than 4 vehicles per hour) where it is assumed that passengers arrive randomly at the stops.

In the case of low frequencies a punctual operation is needed. The worst scenario in this case is driving ahead of schedule: people who miss the bus/tram have to wait the full headway before a new bus/tram arrives. In practice travelers with this experience will go to the stop earlier. In both situations the waiting time is larger than necessary. The average departure punctuality of all lines at all stops in The Hague is 2.1 minutes during morning rush hour. This means the average delay at every stop is plus or minus 2.1 minutes. The reliability level of service defined by the Transit Capacity and Quality of Service Manual (8) is D.

Figure 1A shows the punctuality along the line of one trip (at 8 o'clock PM) of tramline 3 during 1 month. Line 3 operates from Central Station to Loosduinen, a radial line of 11 km. The scheduled headway in that period is long: 15 minutes. It is obvious that a majority of the runs is ahead of schedule, which increases waiting time enormously.

Figure 1B gives the extra waiting time for all travelers at the stops due to the lack of punctuality. This graph clearly indicates the effect of driving ahead of schedule: at the stops where this occurs waiting times increase. The average increase of the waiting time for every traveler on the complete line is 156 s. The average in-vehicle time on this line is approximately 10 minutes, which means that variability results in an increased travel time of about 25% for every traveler, excluding weights for extra waiting time (e.g. 4).



**FIGURE 1 Punctuality (A) and Extra Waiting Time (B) at Stops of Tram Line 3**

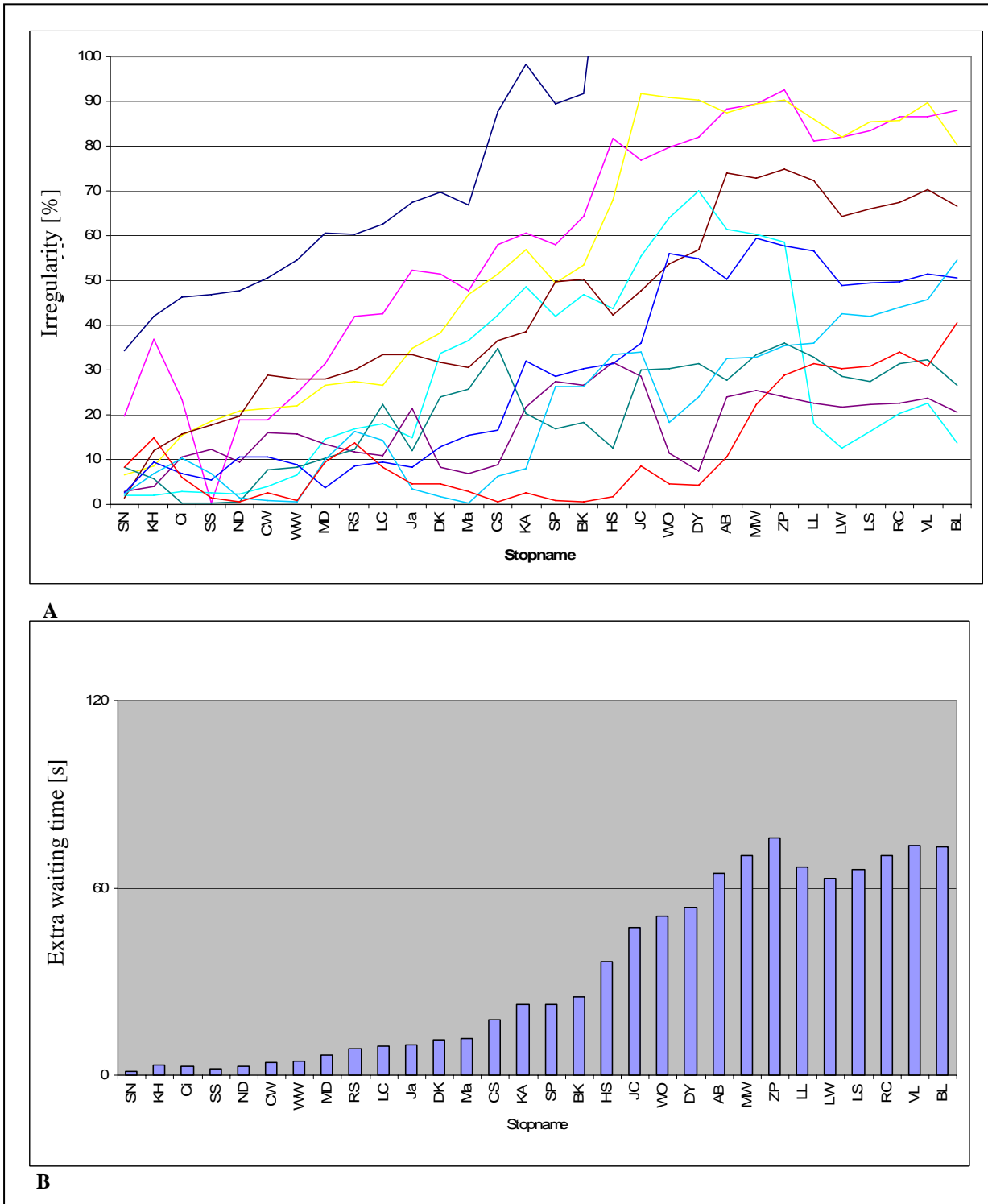
In case of high frequencies, regularity is very important: headways should be equal between all vehicles. Exact departure times are less important. In case of equal headways the average waiting time is minimized and the distribution over vehicles is optimal, which prevents overcrowding (i.e. assuming a uniformly distributed passenger arrival pattern). During morning rush hour, the average irregularity of the lines in The Hague is 26.5%. This number is the average of all stops on a line and indicates an average deviation of actual headways of 26,5% compared to the schedule. Usually the regularity at the beginning of the line is better and it decreases at successive stops. At the end

of the line, regularity is worse than the average value. The reliability level of service defined by the Transit Capacity and Quality of Service Manual (8) is D.

Figure 2A shows the irregularity of some morning rush hour trips of tram line 9. Line 9 operates from Scheveningen to Vrederust, a transversal line of 14 km, having a headway of 5 minutes. The irregularity is quite high, especially at the end of the line.

Figure 2B illustrates the effect of this irregularity for the users: average extra waiting time per stop of the line. This also indicates that travelers at the end of the line are most affected by the irregularity. For all travelers waiting time is increased by 21% related to the 100% regular situation. The travel time thus on average increases with 5%.

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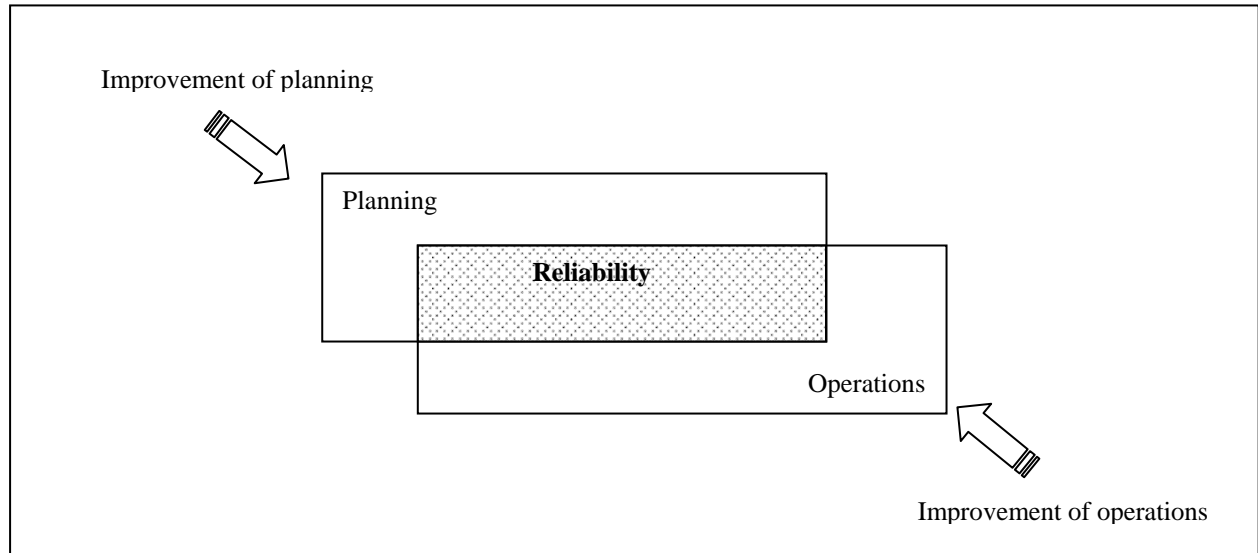
**FIGURE 2 Irregularity (A) and Extra Waiting Time (B) at Stops of Tram Line 9**

In public transport analysis punctuality and regularity are commonly used as supply indicators to measure operational quality. To show the real effects for passengers, extra travel time appear to be a better indicator of service reliability. This way, the effect of driving ahead of schedule and missed transfers are more visible. Punctuality as an indicator is not capable to deal with this explicitly, while the effects may be significant.

#### 4. GENERAL ANALYSIS OF RELIABILITY

The case of The Hague shows that unreliability of the supplied service has a large effect on travel times of customers. Because of the relatively short journeys in urban areas the impact is quite large. In literature as well as in practice a lot of attention is paid to improving reliability at the operational level. Earlier research (e.g. 9, 10 and 11) suggests several solutions to this problem.

However, little attention has been paid so far to prevent these problems by taking reliability into account during the strategic and tactical planning phases of urban transit system design. This paper presents requirements to achieve improvements in reliability by better planning. In heavy railway research there is already attention for this subject (12). Figure 3 shows a visualization of reliability.



**FIGURE 3 Service Reliability in Public Transport and The Role of Planning and Operations**

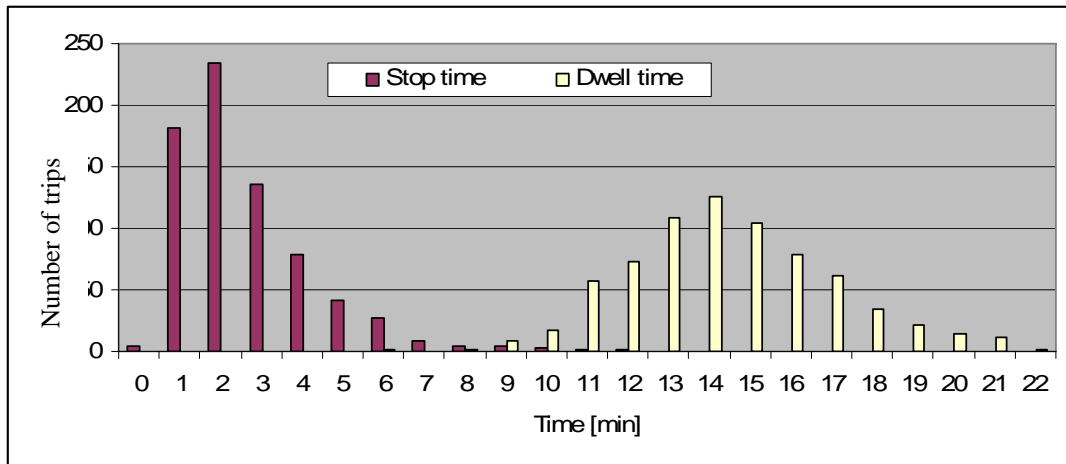
Reliability is defined as the match between planning and operations. Operators offer a network and a timetable, which is their promise to the customer. Reliability defines to what extent they keep to this promise. Since two elements have to match, two ways of improving reliability are possible. By adjusting practice to planning in the one hand and fitting planning to practice on the other hand reliability will be increased. In both ways a higher level of service will be achieved.

##### 4.1 Stochastic Components of Driving Time

Planning and operations consist of several components. The public timetable consists of lines with trip times, frequencies and departure times. For internal planning the layover time is planned as well. During operations all these components are measured and used to improve the schedule. But in contrast to the planning these executed times are stochastic. Trip times can be divided in three parts:

- Driving time: the time spend driving
- Dwell time: the time spend boarding and alighting of passengers
- Stop time: the time a vehicle stops, not for boarding and alighting of passengers

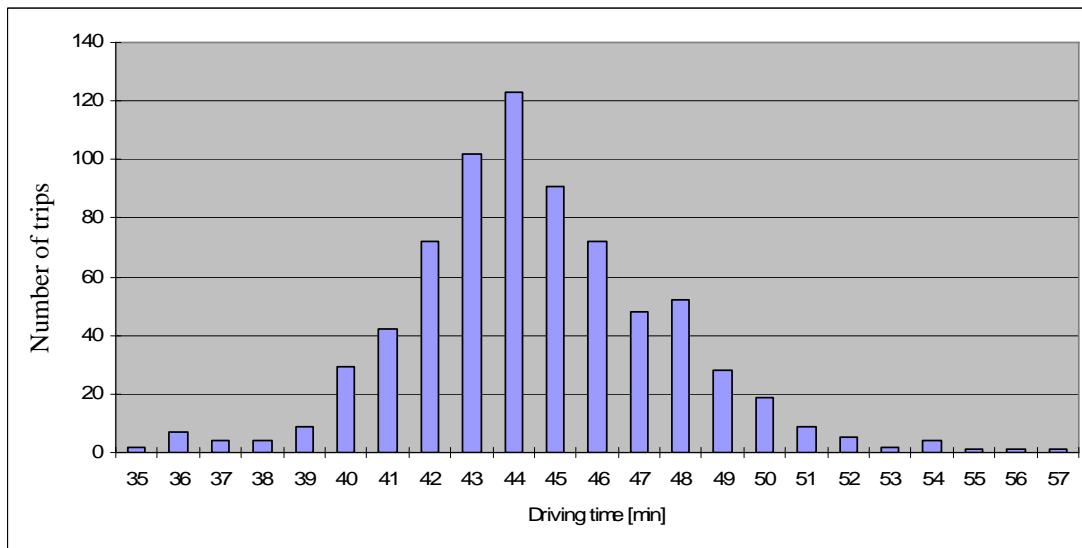
All these components are stochastic and therefore a source for unreliability. Figure 4 and 5 show the distribution of these three components per trip of tram line 1 during the morning peak. Line 1 operates from Scheveningen to the city of Delft, a transversal line of 20 km. The total mean trip time of line 1 is about 60 minutes.



**FIGURE 4 Distribution of Total Trip Dwell Time and Total Trip Stop Time per trip on Tram Line 1**

The average dwell time is 14.5 minutes per trip and the standard deviation is 2.7 minutes. Figure 4 illustrates the distribution in dwell times as a large source of unreliability. Reducing the distribution in dwell time will lead to a higher reliability of this line.

The average stop time is 2.6 minutes per trip and the standard deviation is 1.7 minutes. To achieve a high level of service, operational speed should be high. Reducing stop time is one way to achieve that goal. Well known sources of stopping are crossings, traffic lights and other traffic. In urban areas it is hardly possible to reduce stop time to zero. Therefore it is important to reduce the variation of stop times to achieve high reliability.



**FIGURE 5 Distribution of Total Trip Driving Time per trip on Tram Line 1per trip**

Figure 5 shows the third and main part of trip time: the time the vehicle is driving. As figure 5 illustrates this trip time component is distributed as well. The average value is 44 minutes and standard deviation is 3.1 minutes.

Figure 4 and 5 illustrate that the three main parts of trip time (i.e. driving, dwelling and stopping) are all distributed. To improve reliability attention should be paid to all these components.

**4.2 Improving Reliability**

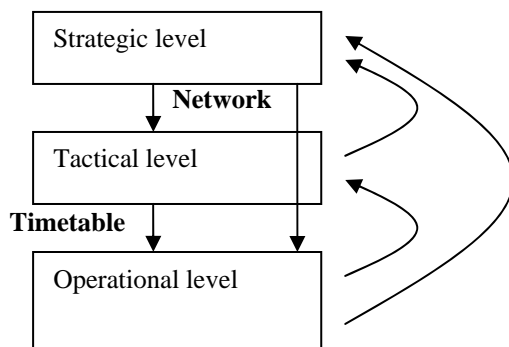
As shown in figure 3 improving service reliability can be done in two ways. First, improvements at the operational level are discussed, after this, possibilities at the strategic and tactical level will be addressed.

The most common way to improve reliability is to make adjustments at the operational level. These adjustments can be done to the operations itself (real time) or to the operations conditions.

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1 The main actor in real time adjustments is the driver. He or she is supposed to drive according to the  
 2 schedule and dependent on his/her behavior and the circumstances he or she will succeed. Important to achieve a  
 3 high reliability is departing on time at the first stop. The driver has great influence on this. Next to the departure  
 4 discipline his or her driving style is an important aspect as well. To achieve a level of high reliability uniform  
 5 driving styles are necessary. To adjust operations in this way training and feedback are important. Another way of  
 6 real time adjustments can be done by dispatchers. In (13) a control system is described, in which both driver and  
 7 dispatcher adjust operations to achieve a better operational performance.

8 Besides real time improving operations, other possibilities to increase quality of service exist as well. By  
 9 improving the conditions for the operations, quality of services can increase too. At all stages of public transport  
 10 these circumstances are created. Figure 6 illustrates the planning stages of public transport. At the strategic level the  
 11 network is designed. This network, with public transport lines and indicative frequencies, is used in the next phases:  
 12 the timetable design and the operational level. At the tactical level the indicative frequencies are extended to a  
 13 detailed timetable which is used by both travelers as well as for the planning of the crew and the fleet. The last level  
 14 is the operational level. During this phase, level of service is measured by several quality indicators. By using  
 15 feedback loops to the upper level these indicators are used to improve quality of the plans.



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24 **FIGURE 6 Planning Stages of Public Transport Services**

25 As mentioned before, much attention is paid to improve reliability at the operational level. However, also  
 26 during the planning phases, improvements are possible. Besides adjusting operations, fitting the schedule as much as  
 27 possible to practice is important as well. Using feed back loops between operations and planning is then necessary.  
 28 The next chapter will present solutions for this, based on a study in The Hague.  
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## 5. IMPROVING RELIABILITY DURING PLANNING STAGES

As mentioned above, during the planning stages of public transport there are possible measures to achieve a higher level of reliability. This paper shows the first results of a quantitative research on this topic in The Hague. Both network and timetable planning are analyzed and different ways of taking reliability into account are examined.

### 5.1 Timetable Planning

When the timetable is planned, information of the operational level is used to achieve high quality timetables. One of the main aspects is driving time. Accurate driving times should be determined to design a reliable and achievable timetable. Because of several disturbances of the operation (because of the stochastic nature of in-vehicle times), the actual driving times are distributed, see Figure 7. In this figure the 15<sup>th</sup> and 85<sup>th</sup> percentile value are shown along the route of tramline 1. Line 1 is a tram line from Scheveningen to Delft. The line length is 20 km and the frequency is 6 times per hour during the analyzed period. At the last stop the difference between these values is almost 10 minutes.

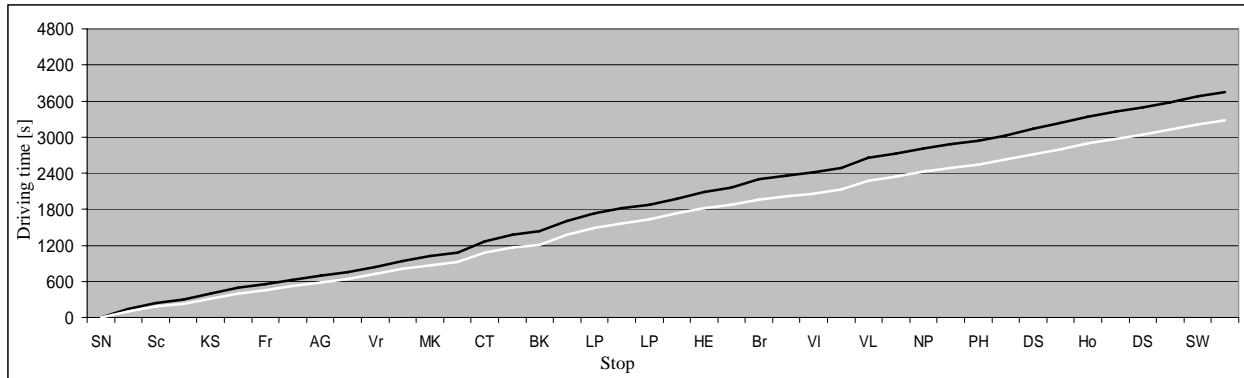
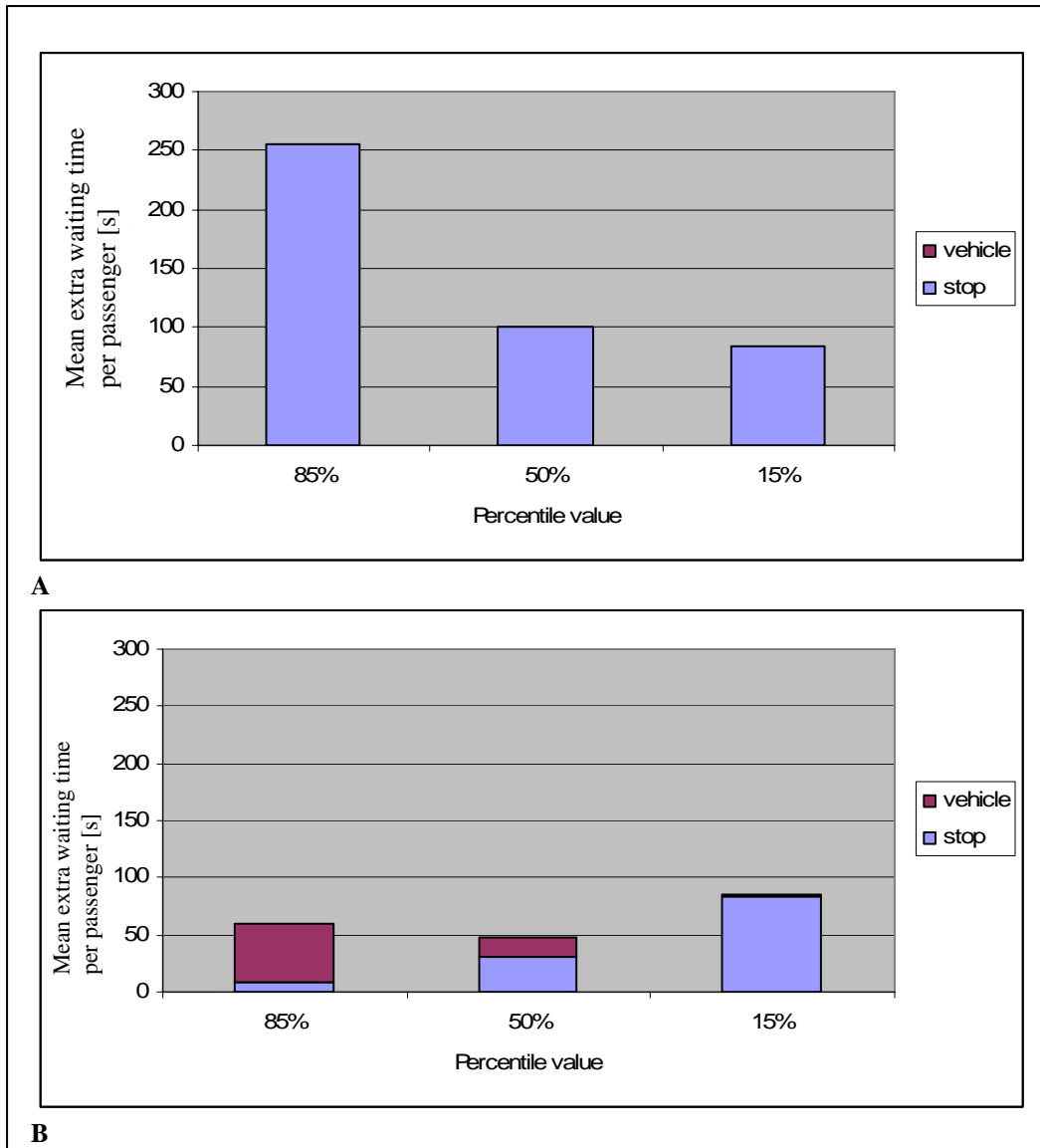


FIGURE 7 15<sup>th</sup> (white) and 85<sup>th</sup> (black) Percentile Values of Actual Driving Times at Stops of Tram Line 1

In urban public transport planning usually a large percentile value of this distribution (e.g. 85<sup>th</sup> percentile) is used to determine the driving time for the schedule. This way, most drivers can operate on time. However, in most conditions this system also influences service reliability: because of large percentile values a lot of trips may operate ahead of schedule (as figure 1A shows). Changing the percentile value will change the number of vehicles ahead of schedule, and thus the punctuality and the extra waiting time.

As an example, three schedules are designed using actual data of line 1 during rush hour in March 2005 (14) to determine the driving time in the schedule. Three different percentile values are used and the effect on extra waiting time for passengers at stops is calculated. Trips that are ahead of schedule lead to waiting times equal to the headway while trips driving late lead to extra waiting equal to the delay. Per stop the mean extra waiting time is calculated according to the punctuality of all trips and after that the mean extra waiting time of the total line is calculated, weighted by the number of travelers per stop.



**FIGURE 8 Average Extra Waiting Time per Traveler Dependant of Percentile Value and Applied Operational Control (A = None, B = No early departures)**

Figure 8A shows that if using the 15 percentile value this results in the least extra waiting time for travelers at stops. This finding is caused by the fact that in that case the number of vehicles driving ahead of schedule is the smallest. In case of using the 85 and 50 percentile values this number of early vehicles is larger, which leads to more travelers experiencing waiting times equal to the headway. This headway is 10 minutes, which is much larger than the actual delays.

The analysis as described focuses on driving ahead of schedule as a source of increasing waiting times and demonstrated the influence of tactical planning. To prevent this, measures can be applied to hold vehicles if they are ahead of schedule. Conditional priority can be applied (11) or drivers can be informed about their punctuality in their cabin (13) and can be requested to wait if they are too early. If a vehicle waits, this means travelers at the successive stops do not experience early departs, but travelers in the vehicle suffer an extra waiting time. A quantitative analysis of this situation has been performed as well, similar to the one described above. The results are given in figure 8B.

Figure 8B shows that if one applies a holding strategy, the 50 percentile value results in the least extra waiting time. In this case the best trade off between waiting for passengers at the stops and passengers in the

vehicles is achieved. If the 85 percentile value is used to design the timetable, the extra waiting time at the stops is little, because almost all vehicles are requested to wait. Since a lot of vehicles are held, the waiting time in the vehicle is large. If the 15 percentile value is used this is the other way around: most vehicles are late, which implies a large extra waiting at the stops and almost no waiting time in the vehicle, because little vehicles are held.

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## 5.2 Network Design

During network planning many choices need to be made. At that stage, reliability is not an explicit design criterion. In this section three design aspects are analyzed taking into account reliability.

### 5.2.1 Line Length

Research (7) shows an increase in variability of driving times along the line. Typically, two lines in the case study are relatively long and suffer from large deviations at the last part of the trip. These lines are tram line 1 and bus line 23. Figure 9 shows the standard deviation at successive stops at these two lines in each direction. At the termini of tramline 1, the average deviation is about 150 and 240 s. At the terminus of bus line 23 it's worse: about 260 and 370 s.



FIGURE 9 Standard Deviation of Driving Times Tram Line 1 en Bus Line 23

The effects for travelers at the last part of the line are substantial. Because of the large deviations the reliability is really low, which increases waiting times. When designing such long lines the effect on reliability should be taken into account. On the other hand of course, splitting these lines in for instance two separate lines would increase the number of transfers. Considering reliability thus introduces new dilemmas in network design.

### 5.2.2 Coordination of Lines

Earlier research (15) describes the effects of coordination of two lines on the same track. It shows that during the design of the network with shared tracks, not enough attention is paid to the effect on the reliability of both lines combined. Already at the strategic level calculations should be made of the expected reliability. Forecast tools and feedback of the operational level are needed to make these calculations.

### 5.2.3 Stop Spacing

One of the biggest sources of deviations appears to be the dwell time. Figure 4 shows the total dwell time of tram line 1. The figure illustrates that the distribution is quite widely dispersed: the minimum is about 6 minutes and the maximum is 22 minutes. These differences occur because of changes in number of passengers. If there are no passengers on a stop and nobody wants to get out, the vehicle doesn't need to stop and there is no dwell time. When designing the network attention should be paid to this variation in total dwell times, especially when determining the stop spacing. To improve reliability it's best to always have some passengers at a stop, ensuring the vehicle stops every time. This prevents large distributions to occur. Of course the optimal stop spacing is a trade off of more aspects (see e.g. 16), but reliability might be taken into account as well.

## 6. CONCLUSIONS

1 Reliability is a key quality indicator for urban public transport. In case of unreliability travelers experience longer  
2 waiting times and thus longer travel times. Especially in urban areas, where the mean travel time is relatively short,  
3 the effect of increased waiting times is significant. Besides, unreliability leads to less comfort as well: due to  
4 bunching of vehicles the chance of having a seat decreases. Uncertainty is the third reason why reliability should be  
5 improved: travelers want to know what to expect when they plan their trip. A case study in The Hague reveals that  
6 unreliability has significant effects: examples of tram lines show an increase in travel time up to 25%. Nowadays, a  
7 lot of attention is paid to improving reliability at the operational level. However, possibilities for improvement also  
8 exist at the planning stages of public transport. During the network and timetable design reliability can already be  
9 taken into account, resulting in a higher level of service (or more easily achievable in practice). For network design  
10 line length and stop spacing are important design parameters which have an effect on reliability. At the timetable  
11 design stage, the method of determining trip times has a great influence. This paper shows a reduction of extra  
12 waiting time by 65% by changing the method for designing schedules. Without any operational control, the 15  
13 percentile value of measured trip times is the best (compared to 50 and 85 percentile) to use. With this value the  
14 extra waiting time for travelers is the least. If control is applied, which implies no early departures, the 50 percentile  
15 value is the best value for trip time with the best trade off between waiting time at the successive stops and waiting  
16 in the vehicle.

17 The analysis in this paper illustrates that possibilities exist to increase the level of reliability in urban public  
18 transport by adjusting the design of the network as well as timetable planning. HTM and Delft University of  
19 Technology continue their research on these topics to achieve a better way of planning of urban public transport  
20 which results in a higher level of reliability.

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