UNRELIABILITY IN PUBLIC TRANSPORT CHAINS

F.R. BRUINSMA
Vrije Universiteit
Department of Spatial Economics
De Boelelaan 1105, 1081 HV AMSTERDAM, THE NETHERLANDS

P. RIETVELD
Vrije Universiteit
Department of Spatial Economics
De Boelelaan 1105, 1081 HV AMSTERDAM, THE NETHERLANDS

D.J. VAN VUUREN
Vrije Universiteit
Department of Spatial Economics
De Boelelaan 1105, 1081 HV AMSTERDAM, THE NETHERLANDS

Abstract
In this paper the reliability of traveling by public transport modes is investigated. We deal with the reliability of travel times in public travel chains. Until now the only research in this field has been directed towards the reliability of trips where only one move is made. Therefore, a new element of our approach is that the probability that passengers miss the connection from one part of a chain to the other is taken into account.

We use a sample of 300 journeys by public transport chains and operationalise them for three different periods of the week (peak hour, off-peak and during the weekend) according to the official time tables as published by the public transport companies. We use the distribution of arrival and departure times - specified for each public transport mode - to simulate disturbances of the travel times compared to official travel times as published by the public transport companies.

INTRODUCTION

Reliability is an important consideration in the choice of transport mode and route. In their choices people act risk-averse: each person tries to reduce the chance of an unreliable movement. Information about reliability is an important factor in the decision process concerned. However, most people make transport decisions with incomplete information. One might argue that the regular traveller is well aware of unreliability. However, he will usually lack information about alternative routes or trips using other transport modes. Given a basis of incomplete information there seems to be a consequent negative perception in many countries of the reliability of public transport compared with the car. In this paper we will focus on reliability of public transport in the Netherlands.

Several studies have shown that the unreliability of travel time is significant in the choice of transport mode and route (see for instance Baaijens et al., 1997). Two components will be analysed in further detail here: deviations from the official time table and the impacts of reliability on transfers. Our focus is the reliability of public transport *chains*. This is a significant topic, particularly because the large majority of research on unreliability addresses the reliability of trips where only one move is made. However, in public transport, chains are quite common and reliability is essential at points of interchange. Ignoring the interchange phenomenon provides only an one-sided view on reliability. Two possibilities for the traveller may emerge: due to unreliability in the first part of a chain, one may miss the connection with the second part of the chain, thus leading to a high degree of unreliability for the total chain. The other possibility is that extra slack at interchange points gives unreliability in the first part of the chain the change to be easily absorbed by the waiting time before the trip is continued.

This short discussion makes clear that unreliability is an important concept for transport service suppliers. For example, hub-and-spoke systems as used in aviation, bus and railway networks depend critically on a reliable service for all vehicles. If a high level of reliability cannot be guaranteed, the operation of hub-and-spoke systems will encounter many problems.

Another implication is that in the construction of time tables by public transport operators there is a clear trade-off between short travel times and reliability. As noted by Ceder (1986), time table construction has received scant attention in the literature and stochastic aspects have usually not been considered (see e.g., Carey, 1994). Shorter travel times in time tables resulting from higher speeds, and shorter waiting times at stops can easily lead to less reliable service because travellers may miss connections, and drivers of buses or trains cannot make up for lost time at earlier stages of the trip.

Another implication of the chain concept is that passengers may be severely inconvenienced when trains depart too early. Therefore, public transport operators should not only worry about drivers departing late, but also drivers departing early.

Finally, an important means of improving reliability of public transport chains is to increase frequencies. This not only leads to shorter waiting times for the next vehicle at points of interchange, but also to less time lost if one misses a connection.

The above observations hold true on a priori grounds. However, the weight they must have in suppliers' decisions cannot be specified until one has empirical information on actual levels of uncertainty. We therefore give an empirical analysis of reliability of public transport chains in the Netherlands.

The paper is structured as follows. We provide a short review of reliability research. We address methods for estimating distributions of departure and arrival times. Next the estimation results for train, bus and metro are given. These results relate to movements of individual vehicles, not to the chains made by passengers. Such chains are operationalised and investigated. The simulation results are presented for a sample of trips, many of them being chains consisting of various parts. Finally we come to some concluding remarks.

ORIENTATION

Reliability may relate to various quality aspects of transport such as the quality of vehicles and the quality of infrastructure as determinants of the likelihood that one will arrive safely. Other reliability factors concern the probability of obtaining a seat in public transport, that certain facilities are open in railway stations, etc. We will focus on a specific aspect of reliability, i.e. reliability of travel times (or arrival times). We introduce three notions:
* official travel time
* actual travel time distribution
* perceived travel time distribution

In public transport the *official travel time* is the travel time according to the published time tables. In private transport the definition is problematic because there is no time table. Here the official travel time may be defined as the travel time needed given an uncongested road, taking into account maximum speed limits and necessary stops at intersections (see table 1). In the case of private transport, the official travel time is therefore more like a distribution around a point rather than an exact figure. Another difference between the official travel time in public and private transport is that the former is general and the latter is individual-specific, since drivers differ in their preferred speed (Rienstra & Rietveld, 1996).

Table 1 - Reliability of travel time for private transport

	Perceived	Objective
General	expected travel time without information about specific circumstances	travel time according to a static route planner not considering congestion
Specific	expected travel time of a specific trip including information about weather, congestion, departure time, etc.	travel time according to a dynamic route planner who includes actual information about congestion

The *actual travel time distribution* represents the travel time outcomes of actual trips. Delays may occur due to a large number of factors. In addition, there may also be travel times that are (slightly) shorter than the official travel times. Again, a difference between public and private transport trips is that the realised travel times of public transport travellers are identical, whereas for private travellers they may differ.

The *perceived travel time distribution* refers to travel times as perceived by the traveller. For experienced travellers, the distributions of actual and perceived travel times may be about equal. However, when travellers do not have experience or lack information about a particular trip, the two distributions may be quite different.

It is important to note that the three concepts depend on external conditions. For example, the official travel time according to the time table may be different on Sundays compared with other days. In addition, the realisations of travel times will vary according to weather conditions, day of the week, time of day, etc. Given these particular circumstances, distributions of travel times show less variation than one would actually have if travellers were not provided with knowledge of such distributions.

We have discussed the reliability of *travel times*; in private transport modes this is equivalent to the reliability of *arrival times*. In public transport this equivalence does not hold, however, since the arrival time not only depends on travel time, but also on departure time. Thus, as will be shown, in the analysis of reliability in public transport chains we have to consider both departure and travel times for a proper analysis of arrival times.

In this paper we will focus on the *actual* travel, departure and arrival times. This is not to say that perceptions are unimportant. Perceptions operate significantly in actual decisions in transport, such as route choice and transport mode (cf. Bovy & Stern, 1990, Fischer, 1993). However, an analysis of

the role of perceptions lies outside the scope of this paper.

As will also be shown, several types of functions are used to study distributions of travel and arrival times.

Departure times are usually strongly asymmetric. Public transport vehicles may depart slightly too early, but the probability of late departures is usually much higher. Therefore, natural candidates for departure time distributions are the gamma, log-normal and Weibull distribution. These are all characterised by a form where the mode is clearly smaller than the median and the mean travel time. These distributions are at the left hand part of their range and are characterised by an increasing probability of departure per time unit (given that they have not yet departed), followed by a decreasing probability of departure at the right hand part of their range.

Special cases of the gamma distribution which are sometimes used are the Erlang distribution and the exponential distribution. The latter distribution has a monotonously decreasing density function implying a constant probability of departure at each point in time given that the vehicle did not yet depart. Given this property, it implausible to use the exponential distribution when vehicles may arrive early.

Based on empirical data for buses, Dauber (1986) concludes that the Erlang distribution is a proper distribution for studying departure and arrival times. In our work we will also consider the log-normal and Weibull distribution.

There are various ways to formulate criteria for reliability. A common measure is to use the probability p that a vehicle arrives x minutes late. Table 2 contains an example for train services in various European countries.

Table 2 - Reliability of train services in various European countries (probability in % that the train arrives at the destination with a delay of less than 5 minutes; 1993).

country	intercity	other trains
Netherlands	91.3	97.1
Germany	82.3	93.6
Belgium	92.6 (not specified)	
France	81.1[1]	93.4
United Kingdom	90.6[2]	92.0

notes: 1: less than 3 minutes
                2: less than 10 minutes
Source: Ministry of Transport (1996).

Other ways to measure reliability are:
• the probability of an early departure,
• the difference between the expected arrival time and the scheduled arrival time
• the expected delay of an arrival given that one arrives late
• the expected delay of an arrival given that one arrives more than x minutes late
• the standard deviation of arrival times
• adjusted standard deviation of arrival time (ignoring the early arrivals) and various other more complex measures to represent the seriousness of unreliability.

These alternative ways of measuring reliability are an input to measure the cost of unreliability. As indicated by Carey (1994), unreliability has to be introduced in cost terms if one wants to trade-off the costs of unreliability with other transport costs, such as the cost of scheduled travel time on links and waiting time at stations/stops. The unreliability-related costs are the expected costs of arriving later or earlier than scheduled at a stop, and the expected costs of departing later or earlier than scheduled at a stop. In this paper we do not explore the optimisation of time tables; therefore there is no need to define unreliability explicitly in cost terms.

METHODS FOR ESTIMATING DISTRIBUTIONS OF DEPARTURE AND ARRIVAL TIMES

In this section we explain our methodology for estimating the distribution functions of deviations from the departure and arrival times of the various public transport vehicles. As candidates for the distribution functions we take the gamma, the log-normal and the Weibull distribution. These distributions have a common feature in that they have a unique mode and finite expectation and variance. Whereas the standard gamma, log-normal and Weibull distributions are all defined on the positive half axis, we introduce a third parameter to all distributions; the location parameter m. This parameter is chosen such that it is identical to the mode of the particular distribution. If the shape parameters are rightly chosen (i.e. smaller than 1), the modes of the gamma and the Weibull distribution are not equal to the minimum value. For the log-normal distribution this is always the case. In practical situations this is often a desirable property - both for departure and arrival distributions -, whereas it may allow early departures and arrivals. The formal expressions for the cumulative distribution functions are as follows:

$$
\text{Gamma}: \qquad F(t) = \begin{cases} F^s\left(t - m + \dfrac{\alpha - 1}{\lambda}\right) & \text{if } \alpha \le 1 \\ F^s(t - m) & \text{if } \alpha > 1 \end{cases}
$$

$$
\text{Lognormal}: \qquad F(t) = F^s\left(t - m + \exp(\lambda - \alpha^2)\right)
$$

$$
\text{Weibull}: \qquad F(t) = \begin{cases} F^s\left(t - m + \dfrac{(1 - 1/\alpha)^{1/\alpha}}{\lambda}\right) & \text{if } \alpha \le 1 \\ F^s(t - m) & \text{if } \alpha > 1 \end{cases}
$$

We indicate the standard (two parameter) distribution functions with the superscript s. Explicit expressions for these distribution functions can be found in most statistics textbooks, see e.g. Tijms (1994). It is understood that the exponential (λ, m) distribution equals the Gamma $(\lambda, 1, m)$ and the Weibull $(\lambda, 1, m)$ distribution.

In order to obtain a classical maximum likelihood estimation of the parameters of a cumulative distribution function, one should have a set of observations of times. In some cases however, the data is delivered in frequency form: the real axis is divided into a number of intervals, and the numbers of observations in these intervals are counted. We therefore have to use a slightly different estimation procedure, which is a discretised version of the classical maximum likelihood estimation procedure. Denote the number of observations by S, and the n-th interval by $I_n = (d_n, d_{n+1}]$ for n = 1,..,N-1. Here N is equal to the number of intervals. Of course we assume that $d_{n+1} > d_n$ for all n, implying that all intervals are disjointed. Furthermore, denote by p_n the fraction of the data that was located in the interval I_n. The likelihood function can now be written as

$$
L(\lambda, \alpha, m; d, p) = \prod_{n=1}^{N} \{F(I_n; \lambda, \alpha, m)\}^{Sp_n} \tag{1}
$$

The described method can be applied directly to estimate the cumulative distribution function of the deviations from the departure and arrival times. When possible, one may also want to estimate the conditional arrival time distribution, conditional on the departure time deviation. The reason for this is that when one is evaluating a particular transport chain chronologically, the conditional arrival time distribution is more relevant than the ordinary arrival time distribution. The estimation procedure is however, less straightforward. In order to develop an estimation procedure, we consider the following fundamental relation:

$$
T_A = T_D + T_R \tag{2}
$$

where:

T_A = arrival time
T_D = departure time
T_R = travel time

It is important to realise that this relation holds both in a deterministic and a stochastic setting. Subtracting the deterministic version of (2) from the stochastic version yields

$$A = D + R \tag{3}$$

where:

A = deviation from the scheduled arrival time
D = deviation from the scheduled departure time
R = deviation from the scheduled travel time

In the following we will have to make the following assumption:

Assumption A1. The covariance between the deviation from the scheduled departure time and the deviation from the scheduled travel time equals zero:

$$Cov(D,R) = 0.$$

We must make this assumption when there are no paired data available on departure and arrival time deviations (this is the case when surveyors collect data at stations, bus stops, etc., and not in the public transport vehicles themselves). At first sight the assumption may seem too heavy, but one should realise that a zero covariance is not equivalent to independence of the stochastic variables. It is highly possible that opposite effects cancel each other out: on the one hand the driver may be able to correct the departure time delay during a trip, on the other hand, it often happens that delays accumulate. This last possibility can be seen, for example, in train traffic in the area of a junction. In terms of cumulative distribution functions, (3) can be rewritten by means of a convolution:

$$F_A(a) = \int F_D(a - \varepsilon) f_R(\varepsilon) d\varepsilon \tag{4}$$

We use the convention that the capital letter F represents a cumulative distribution function (cdf), and the small letter f represents a density function. The subscripts are aimed at the corresponding stochastic variables. Assume now that the cdf of the departure time deviation is already known (e.g. by the discretised maximum likelihood procedure that was explained above). Denote by ϑ the parameters of the cdf of the travel time deviation R. Equation (4) may then be rewritten as

$$F_A(a; \vartheta) = \int F_D(a - \varepsilon) f_R(\varepsilon; \vartheta) d\varepsilon \tag{5}$$

We assume that the data are once again delivered in frequency form with intervals $J_n = (a_n, a_{n+1}]$ with $a_{n+1} > a_n$ for n = 1,.., N-1. Denoting by q_n the fraction of the data that is located in the interval J_n, the likelihood function can be written as

$$L(\vartheta; a, q) = \prod_{n=1}^{N} \{F_A(J_n; \vartheta)\}^{Sq_n} \tag{6}$$

where F_A is given by (5), and S stands for the sample size. The parameters can again be estimated by the well-known maximum likelihood technique. Once we have obtained an optimal distribution for the travel time deviation, it is easy to derive an expression for the cdf of the conditional arrival time deviation:

$$F_A\left(a|D=d;\vartheta_{MLE}\right)\equiv Pr\left\{A\le a|D=d;\vartheta_{MLE}\right\}$$
$$=Pr\left\{V+R\le a|D=d;\vartheta_{MLE}\right\}$$
$$=Pr\left\{R\le a-d;\vartheta_{MLE}\right\}$$
$$\equiv F_R\left(a-d;\vartheta_{MLE}\right)$$

The estimation of the conditional arrival time deviation cdf thus boils down to the estimation of the travel time deviation cdf, according to (5) and (6). A feature of this estimation procedure is that the integral in (5) has to be computed numerically; efficient algorithms are available for this purpose. In the next paragraph we will give estimation results for the departure time deviations and arrival/conditional arrival time deviations.

ESTIMATION RESULTS

The methods described in the previous section are used to estimate the cdf's of departure and arrival/conditional arrival time deviation of several public transport modes in the Netherlands. In the following we will discuss the distribution functions that give the best (maximum likelihood) fit to our data. First we give a brief overview of the data.

Urban bus and tram: For these means of transport, we use data from the municipality public transport company in Amsterdam (GVB). The realised departure and arrival times of three bus lines and three tram lines in Amsterdam during the winter of 1996 have been compared with the scheduled times. We make a distinction between trips during morning peak hours (7 am to 9 am) and off-peak hours (11 am to 1 pm) on workdays and also trips on Sundays between 11 am and 1 pm. The number of observations is equal to about 600-700 on weekdays and 130 on Sundays.

Train: The data, which concern 10 weekdays and four Sundays in March 1997, are obtained from the Dutch national railway company, the NS. A distinction has been made between two types of trains: intercity trains and stopping trains. It has also been possible to discriminate between trips during peak hours and off-peak hours on weekdays and trips on Sundays. The number of observations is equal to about 7100 and 4300 on weekdays for the stopping train and the intercity train respectively, and 2200 and 1700 on Sundays.

Inter-urban buses: The data are from the inter-urban bus company BBA in the Dutch province of Noord-Brabant. During the period September-October 1996, a data set of 1471 observations was completed. In the data set no distinction has been made between trips on different times/days.

Underground: The data for the underground were collected at the RET in Rotterdam, during the period 21-22 September 1982. The number of observations is equal to 418. In the data set no distinction has been made between trips on different times/days.

Estimation results are given in figure 1 for a sample of transport modes. It is seen from the figures that for the trains, although the means are near to zero, the variances may be substantial. The underground appears to be more reliable: the means are very close to zero, and the variance is quite small.

It can be seen that on Sundays, train traffic is more reliable than on weekdays; during peak hours throughout the week it is least reliable. During peak hours the intercity train performs better, but during off-peak hours the stopping train performs better. More details of the estimation results can be found in Bruinsma et al. (1998).

SELECTION OF THE PUBLIC TRANSPORT CHAINS

To achieve a representative set of public transport chains, the 1994 travel behaviour survey (OVG) of the Dutch Statistical Office (CBS) was used. This survey contains data on trips of a large number of respondents who have recorded their travel behaviour in a diary. The survey has a national

coverage.

The sample used in this research project has been stratified by urbanisation level and trip length. For each combination of urbanisation level and trip length a sample of 15 trips is selected. The sample contains 300 trips. In table 3 the total number trips of each cell are given, so we can weigh the sample to make statements representative of the travel behaviour in the Netherlands.

The 300-trip sample has been operationalised by requesting at the Public Transport Travel Information Agency (OVR) travel schemes, complete with frequencies for the next connection, for three periods of the day: the morning peak hour (7.30), during the off-peak hours (13.00), and on Sunday (11.00). Our data set therefore contains data on 900 trips.
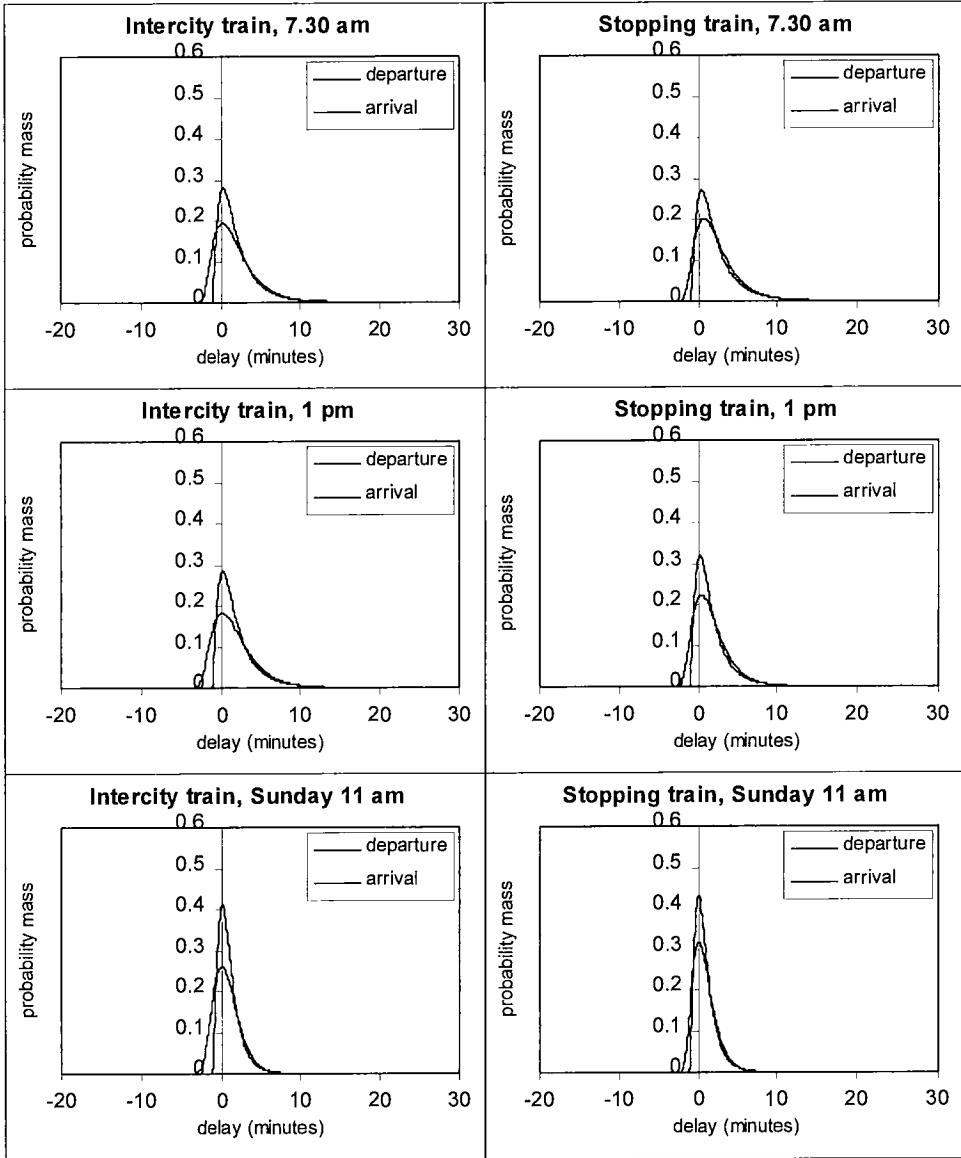

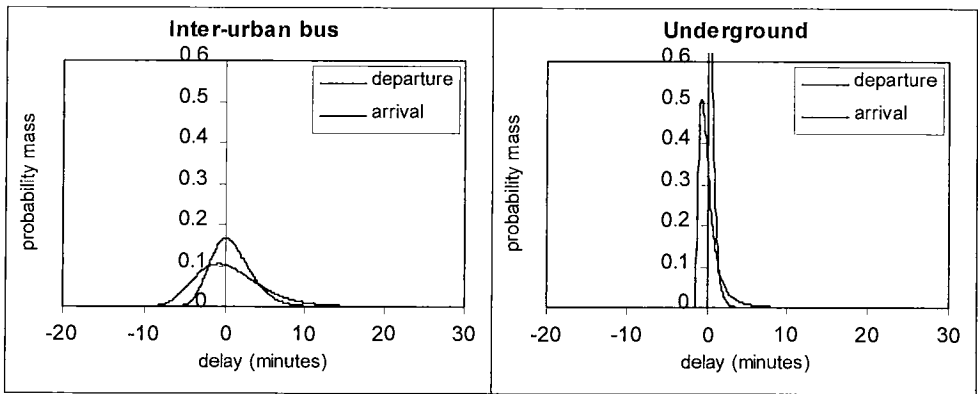Figure 1 - Estimated departure and arrival time deviations

Figure 1 (continued) - Estimated departure and arrival time deviations

The ten most common public transport chains (weighted by level of urbanisation and length of trip) are given in table 4. In the before and after part of transport chains the bus is often used. In reality, this will less often be the case, and frequently, the bicycle will be used for such purposes. However, the Public Transport Travel Information Agency does not include this option in its travel advice.

Table 3 - Number of public transport trips in the travel behaviour survey (4306)

	highly urban	strongly urban	urban	hardly urban	not urban
< 7.5 km.	385	187	131	71	99
7.5 - 20 km.	373	251	271	267	271
20 - 50 km.	190	248	326	292	277
> 50 km.	87	155	144	153	128

Source: CBS (1994)

Table 4 - Most common public transport chains in the sample (in %)

morning peak	off-peak	Sundays	chain
26.3	25.4	25.4	bus
19.6	22.1	17.7	bus/bus
12.8	11.1	13.8	bus/train/bus
9.9	7.4	8.8	train/bus
5.2	4.8	3.7	bus/bus/bus
4.8	6.1	3.6	bus/train
4.7	6.0	7.0	bus/train/train/bus
3.1	2.4	3.7	train
2.4	1.8	1.4	bus/train/tram
2.4	2.0	0.8	tram/train/bus

SIMULATION RESULTS FOR PUBLIC TRANSPORT CHAINS

We now present the results of simulations on the 300 public transport chains as selected and operationalised above. Each public transport chain has been simulated 2.500 times for trips in the morning peak, the off-peak period, and on Sundays. Eighteen chains could not be simulated on Sundays because the public transport services concerned were not provided on Sunday.

In figure 2 the distribution of arrival times is given for the morning peak hours. The figure shows that most trips arrive within an acceptable margin of the official scheduled arrival time. Next the figure shows the impact of the frequencies of the services offered; the figure shows peaks in delays of 30, 60, and 120 minutes.
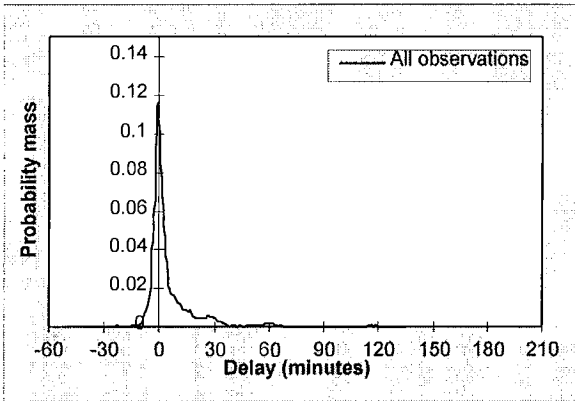

Figure 2 - Arrival time deviations for public transport chains

Irrespective of the period of the day, there is an expected delay in travel time of about 10 percent compared to the official scheduled travel time (see table 5). The total average travel time is shortest during the morning peak and longest on Sundays. According to the official time table and the

Table 5 - Average scheduled and simulated arrival times in the morning peak, off-peak hours, and on Sundays

	morning peak	off-peak	Sundays
average scheduled travel time	59.9 min.	61.8 min.	65.1 min.
- of which waiting time	5.1 min.	6.4 min.	8.7 min.
average simulated travel time	65.9 min.	67.9 min.	72.5 min.
- of which waiting time	10.7 min.	12.1 min.	15.4 min.
extra travel time (simulated versus scheduled, %)	10.0 %	9.9 %	11.4 %
arrival at least 2 min. early	0.5 %	0.7 %	0.8 %
arrival 0 - 2 min. early	30.1 %	29.6 %	31.7 %
arrival as scheduled	12.0 %	11.6 %	12.7 %
delay 0-5 min.	30.4 %	29.7 %	31.2 %
delay 6-10 min.	8.8 %	9.7 %	6.5 %
delay 10-30 min.	13.2 %	12.7 %	9.1 %
delay over 30 min.	5.1 %	6.1 %	8.0 %

simulations, this is mainly caused by the increase in waiting time, due to the frequencies in services that are high during the morning peak and low on Sundays.

Regardless of the time of day in about 30 percent of the chains passengers arrive *before* the scheduled arrival time. However, the number of times one arrives over two minutes before the scheduled arrival time are rare. More important is the fact that about 30 % of the trips have a delay of over five minutes.

Selection of common public transport chains

Next to the general overview given above, five types of public transport chains have been selected as good representatives for the diversity of chains. In table 6 the average travel times for each selected type of public transport chain are given. Columns 1-3 give the *scheduled* travel time for trips during the morning peak hour, the off-peak hours, and on Sundays, respectively. Columns 4-6 give the average *simulated* travel times as a percentage of the respective scheduled travel times.

Table 6 - Average scheduled (in minutes) and average simulated (as a percentage of scheduled) travel times for some selected types of public transport chains

	average scheduled travel time			average simulated travel time as a % of the scheduled travel time		
	morning peak	off-peak	Sundays	morning peak	off-peak	Sundays
bus	28.8	28.7	28.1	100.3	102.4	101.1
bus/bus	50.5	54.5	55.2	106.1	106.4	110.9
train/bus	53.7	60.7	65.3	109.5	103.6	109.6
bus/train	58.0	55.2	64.6	108.8	109.2	102.3
bus/train/bus	74.3	71.0	85.5	111.6	111.8	110.5
all chains	59.9	61.8	65.1	110.0	109.9	111.4

As might be expected, there are large differences in the average travel time for the selected eight types of public transport chains. The average scheduled travel time increases with the number of transfers included in the chain. The average travel time of chains with only one transfer is about one hour, whereas in the case of chains where three transfers are necessary the average travel time is nearly 2.5 hours.

Columns 4-6 show the simulated average travel time in relation to the scheduled travel time for that specific period of the day. This allows us to make comparisons both according to the type of public transport chains, and the period of the day the trip takes place.

After having discussed average travel times we will now discuss the *distribution* of arrival times. In table 7 for the different periods of the day the percentage of trips arriving on (or before) scheduled arrival time, and the percentage of arrivals at least five minutes delayed are given. While a delay of five minutes on a trip of half an hour or on a trip of two hours makes a difference, the average travel time is also given.

The table shows that irrespective of the period of the day on a one-hour trip one should expect a delay of over five minutes every fourth or fifth trip. There are only a few chains where there are large differences in the percentage of trips causing more than five minutes delay depending on the period of the day the trip is taken. For example, the train/bus chain shows a relatively high percentage of trips in the morning peak with a delay of over five minutes compared to off-peak hours and in particular Sundays.

Table 7 - Travel times and distribution of arrival times by different periods of the day

chain	morning peak			off-peak period			Sundays		
	average travel time (min.)	% of arri- vals in time	% with delay > 5 min.	average travel time (min.)	% of arrivals in time	% with delay > 5 min.	average travel time (min.)	% of arrivals in time	% with delay > 5 min.
b	28.9	64.5	3.0	29.4	56.8	6.7	28.4	62.0	5.6
b/b	53.6	48.1	17.9	58.0	46.5	20.3	60.7	46.0	20.1
t/b	58.8	46.9	28.7	62.9	47.5	19.3	71.6	47.2	14.6
b/t	63.1	28.0	24.9	60.3	39.1	27.7	66.1	49.1	18.0
b/t/b	82.9	33.0	36.6	79.4	28.8	41.4	94.5	37.9	31.1
all	65.9	42.6	27.1	67.9	41.8	28.5	72.5	45.2	23.6

In figure 3 the variation in arrival times is shown in diagrams for chains where respectively one, two or three transfers are included. The bus/bus chain shows the impact of the low frequencies of the inter-urban buses. By considering the peaks in the diagram, one can see that missing a connection to a regional bus leads to a delay of half an hour, an hour, or even two hours in the worst cases. In chains with two transfers - in this example the bus/train/bus chain - those peaks are not so clearly visible.
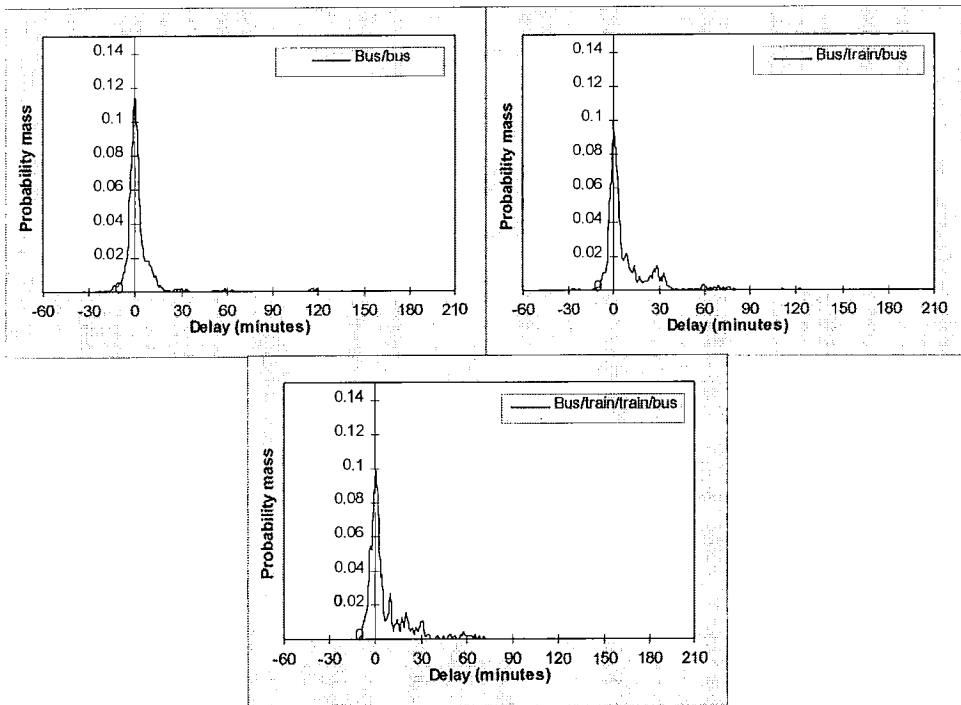

Figure 3 - Arrival time deviations for public transport chains

The impact of distance

To measure the impact of distance we used the four distance categories mentioned in table 3. As expected, the average travel time increases by increasing distance. It appears that the simulated travel time is between 7 and 10 % higher than the travel time according to the time table for three of the four distance categories, irrespective of the time of the day the trip is taken. For the fourth distance category - the category 7.5 - 20 km - the simulated travel times are about 14 % higher in the case of the morning peak, and the off-peak trips, and 17 % higher for trips on Sunday. The public transport services apparently do have difficulties keeping on schedule for those distances; the 7.5 - 20 km distance category is an important distance range for commuting in the Netherlands.
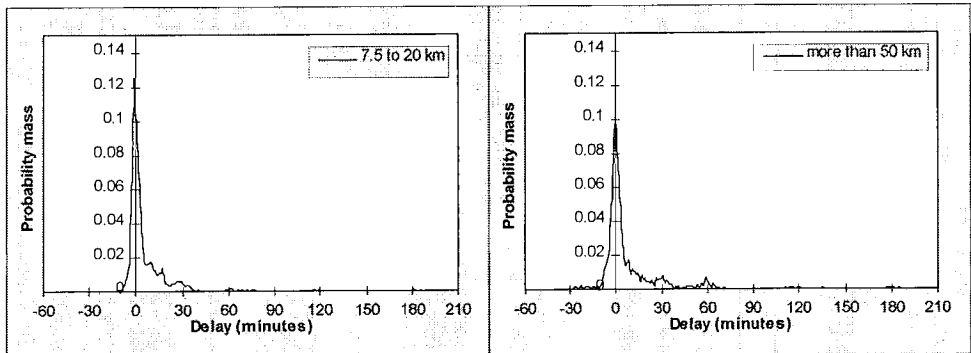

Figure 4 - Arrival time deviations for public transport chains

The variation in arrival times also increases by increasing distance. In the shortest distance category - trips shorter than 7.5 km - about 50 % of the trips arrive on time or a bit early, and less than 20 % has over a five minute delay. In the longest distance category - trips of at least 50 km - the opposite is seen; nearly 40 % arrives as scheduled, and over 30 % has at least a five minute delay. In figure 4 this is shown for the distribution of the arrival times during the morning peak. Although the tail of the distribution diagram of the longest distance category is clearly thicker than the tail of the category 7.5 - 20 km, it is noteworthy that even on those relatively short distances of less than 20 km, it may be possible to be delayed by two or three hours.

CONCLUSION

A substantial number of trips made by public transport are chains consisting of more than one link. Therefore, whenever unreliability in public transport is studied from the uni-modal perspective of individual suppliers the result is an incomplete picture, because the probability that travellers miss connections was not included.

Based on a sample of public transport chains in the Netherlands, we use data on unreliability of individual transport modes to simulate the degree of unreliability in the total chain for various parts of the day (morning peak, off-peak, and Sundays). We find that about 40-45% of travellers arrive according to schedule (or slightly earlier), about 30% has a delay of 0-5 minutes; the rest (25-30%) has longer delays. The average travel time of the realised chains is about 10% higher than the scheduled travel time. *Most of the extra travel time is spent as waiting time on platforms* because unreliability implies that travellers miss connections.

A comparison of the unreliability of the services in the morning peak, off-peak, and on Sundays reveals that on average the differences are small. The reason is that the higher reliability of individual transport modes on Sundays goes hand-in-hand with lower frequencies. The latter aspect leads to long waiting times in the event that a connection is missed.

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