THE IMPACT OF TRAVEL TIME UNRELIABILITY ON THE CHOICE OF RAIL, ACCESS MODE AND DEPARTURE STATION

Martijn Brons, European Commission, Joint Research Centre (JRC), Institute for Prospective Technological Studies (IPTS), c/Inca Garcilaso 3, 41092 Seville, Spain.

Piet Rietveld, Department of Spatial Economics, Vrije Universiteit, De Boelelaan 1105, 1081 HV Amsterdam, the Netherlands.

ABSTRACT

This study analyses the impact of travel time unreliability on choice behaviour of the rail passenger, based on Dutch data at the 4-digit post code level. Adopting a customer-oriented approach, the paper studies a variety of choices in different stages of the door-to-door rail journey, viz. the choice to travel by rail or car, the choice of access mode and the choice of departure station. Furthermore, the study analyses and compares the impact of different travel time unreliability indicators, including measures based on travel time variety, size of delay, and punctuality. In order to analyze the choice behaviour of rail passengers, the study uses a combination of binary and nested logit modelling. The estimation results show that travel time unreliability has a significant impact on the choice for rail as a transport mode, that differences in travel time unreliability among railway stations have an important impact on the choice of departure station, and that high travel time unreliability of the rail trip is associated with a low share of public transport as an access mode. Furthermore, it is found that unreliability measures based on travel time variation capture the passenger's perception of unreliability better than measures based on the size of the delay or the probability of delays, such as currently used in most countries to measure railway reliability performance.

Keywords: Travel time unreliability, Rail transport, Discrete choice modelling, Multimodal transport

1. INTRODUCTION

Increasing levels of congestion, growing awareness of climate change and the notion of peak oil constitute some of the most important global challenges today. European policymaking views the promotion of sustainable mobility as one of the key objectives of transport policy (see European Commission, 2001). Railway is the natural backbone of any sustainable transport system, offering efficient transport built on social equity, low carbon emissions, low environmental impacts and positive economic growth. Hence, improving the position of the railways is one of the main elements in the transition towards sustainable mobility. Maintaining rail service quality is safeguarded by policymakers through concessions in which railway operators are typically held accountable for measurable indicators of quality aspects, such as punctuality. At the same time, the ambitions of European rail operators, including the Dutch Railways, as reflected by company mission and media statements, tend to develop towards a more customer-oriented focus. As it is ultimately the traveller who makes the choice to travel by rail or not, the transition towards a customer-oriented approach seems to provide more potential for improving the position of the railways than a pure process-oriented focus and should therefore be adopted and supported by policymakers.

For most trips by rail, the car is the closest substitute and often the only viable alternative. Hence, the success of the railway sector can be assessed by the share of rail trips in the total number of trips by rail or car. An analysis of the choice between rail and car is carried out in Brons et al. (2009). However, a customer-oriented approach need take into account the fact that the choice of the traveller is not only determined by characteristics of the rail trip itself but by characteristics of each of the stages in the door-to-door rail journey, which include also the access trip to the departure station and the time spent on the departure station and transfer station(s). Using customer satisfaction data from the Dutch Railways, Brons and Rietveld (2008) analyze, based on derived importance regression techniques, the relative importance of ten dimensions of the door-to-door rail journey, and conclude that travel time unreliability is the second most important dimension, just behind travel comfort. Unlike travel comfort, travel time unreliability receives a low average satisfaction score. According to the marketing literature on customer satisfaction (e.g. Hawes and Rao, 1985; Kristensen et al., 1992; Slack, 1994; Bacon, 2003), the combination of high importance and low satisfaction classifies travel time unreliability as a ‘problem area’ which requires improvement in order to increase the satisfaction with the door-to-door rail journey. It would be interesting to analyze to what extent such improvements in travel time unreliability affect the actual choice of using the rail mode instead of the car.

For each rail trip, the rail traveller can choose between multiple departure stations.[1] The choice of departure station is likely to be determined by travel time unreliability (together with other station characteristics such as accessibility and rail network service). Improving the travel time unreliability on railway stations may therefore increase the share of rail passengers attracted. Improving travel time unreliability at railway stations located near residential areas, may lead to an increase in the share of access trips to these stations and thus a decrease in the average access trip distance. In

[1] For the average traveler, three stations are realistic departure points. An analysis of Dutch Railways data on shares of departure stations for 1440 4-digit postcode areas shows that the first station in a postcode (in terms of the share of rail trip departures) attracts on average 83.9 percent of the postcode’s rail trip departures. The first and secondary stations together attract on average 94.7 percent of the rail trips and the first three stations attract 97.5 percent

addition to a decrease in access mode mobility this may result in a shift towards 'green' access modes such as bicycle and walking. Hence, insight into the impact of travel time unreliability on the choice of departure station is interesting from a sustainable mobility viewpoint.

While rail operators are principally interested in attracting rail passengers, policymakers motivated by sustainability considerations prefer to attract rail passengers using 'green' access modes. Improving travel time unreliability on a station may increase the connectivity and thus accessibility with scheduled modes and hence lead to an increase in the use of public transport as an access mode. For policy makers it is interesting to know if an improvement in the travel time unreliability indeed leads to a shift towards the use of public transport as an access mode and away from unscheduled travel modes, and furthermore, if this constitutes a shift away from motorized access modes or non-motorized access modes.

Travel time reliability is probably the most commonly used indicator to measure reliability of rail transport operators. In the Netherlands, the Dutch Railways are being held accountable by the Ministry of Transport for the so-called 'punctuality' of trains, measured at thirty-five important rail interchange points in the Netherlands (Nederlandse Spoorwegen, 2006). A train is considered to be punctual if it arrives within three minutes of delay.[2] It is questionable whether such a process-oriented approach of reliability corresponds very well to the customer-oriented ambitions of the Dutch Railways. Brons and Rietveld (2010), formulate a number of points of critique on the use of punctuality as a reliability indicator, including the following. First, apart from the somewhat arbitrary punctuality margin of three minutes, no particular weight is attached to the size of the delay; a delay of forty minutes has the same effect on the punctuality as a delay of four minutes. It is questionable whether this is very realistic from a passenger's point of view. Second, no particular weight is given to the variation in arrival times of trains. One could argue that the passenger's perception of unreliability includes elements of unpredictability rather than only adherence (or lack thereof) to time tables. Third, negative consequences of delays on departure are not taken into account. Extra waiting time caused by a delayed departure results in a loss in utility, even if the train arrives in time at the final destination. Furthermore, departing late may result in missing connections and hence to even more substantial time losses than late arrivals at the final destination. These points of critique raise the question whether the punctuality indicator fully captures the actual disutility of the rail passengers caused by travel time unreliability, or if certain alternative indicators of travel time unreliability may be more appropriate in this respect.

This paper aims to analyse the impact of travel time unreliability on (i) the choice whether or not a passenger will make use of rail transport, (ii) the choice of access mode to reach the railway station and (iii) the choice of departure station. Furthermore, the paper will focus on a comparison among the size of the impacts of the different

[2] Until 1999, the Ministry of Transport adhered to the international standard of a margin of five minutes.

indicators and specifications of travel time unreliability, so as to analyse which indicator captures best the perception of unreliability of the rail passenger. We investigate two indicators based on punctuality, i.e., (i) the percentage of trains with more than three minutes of delay (3MIN), and (ii) the percentage of trains with more than nine minutes of delay. The 3MIN indicator corresponds to the indicator used by the Dutch Railways, but is measured as the percentage of non-punctual instead of punctual trains in order to facilitate comparison with the other indicators. The 9MIN indicator is an alternative indicator that allows us to investigate whether the three-minute margin is really arbitrary or not. In order to investigate the importance of the size of the delay we employ two indicators that express delays in number of minutes, i.e., the average delay in minutes (AVMIN) and the average delay of non-punctual trains (AVMIND). In order to investigate the importance of travel time unpredictability we employ two indicators based on the statistical distribution of arrival and departure times, i.e., (v) the 80th minus 50th percentile (PERC) and (iv) the standard deviation (STDEV). These two indicators also include effects of early arrivals and departures. **Error! Reference source not found.** displays a graphical representation of the approach.

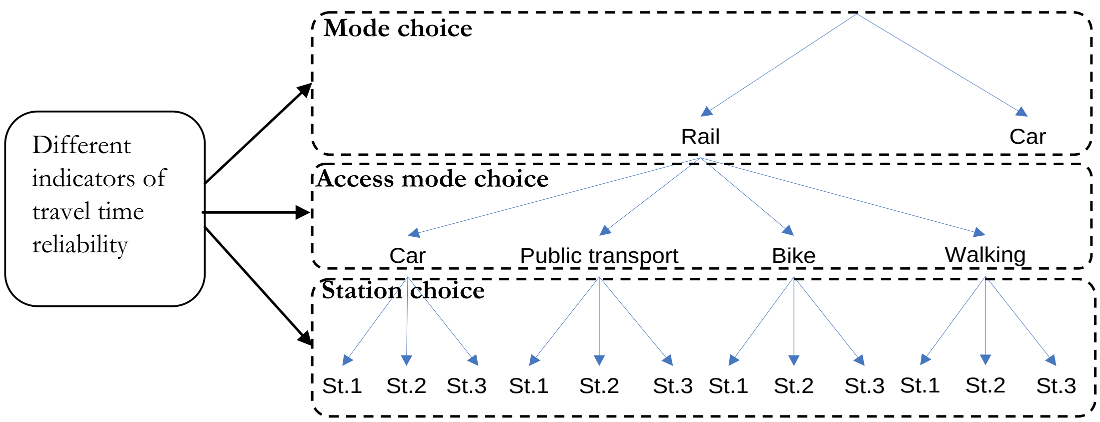


Figure 1: The impact of travel time unreliability indicators on various choices in the door-to-door rail journey

The structure of the paper is as follows. In Section 2, we give an overview of the data that we use for the analysis. Section 3 discusses the results of a series of descriptive statistical analyses on rail share, access mode share and departure station share in the Netherlands. Section 4 contains the main analysis of the study. Section 4.1 discusses the results of the estimation of the impact of travel time unreliability on the choice between rail and car, while Section 4.2 discusses the impact on the choice of departure station and access mode. Based on the estimation results in Section 4.1 and 4.2, Section 4.3 will analyze the effect of a number of scenarios of improvement in travel time unreliability on the total number of rail trips, access trips with various modes and departures from different types of stations. Section 5 provides conclusions and policy implications.

2. DATA

The analysis is carried out at the four-digit postcode level, and is based on 1440 postcode areas. For each of the postcode areas, the share of rail use is calculated as the number of rail trips per person per day divided by the number of trips by either rail or automobile per person per day; data on rail use was obtained from the Dutch Railways and data on car use from CBS-Statline. Data on station choice and access mode choice were also obtained from the Dutch Railways. For each of the 4-digit postcode areas, the set of three most frequently used departure stations is identified (in total 346 railway stations are included in the analysis). For each postcode area the share of passengers choosing each of the three stations is determined. Furthermore, a set of four alternative access modes is defined, i.e., car, public transport, bicycle and walking. All four access modes are assumed to be available alternatives in each postcode area. For each of the postcode areas, the share of each of the access modes is determined.

Table I: Overview of explanatory variables

	Variable	Abbreviation	Mode choice (train vs car)	Station choice	Access mode choice
	Rail network service index	NET	×	×	×
Accessibility	Distance to station	DIST	×	×	×
	Public transport travel time	TT	×	×	×
	Public transport frequency	FREQ	×	×	×
	Guarded bike parking	BPARK	×	×	×
	Park and Ride facility	PNR	×	×	×
	Cars per household	CAROWN	×	×	×
TTU	% trains delayed more than 3 min	3MIN	×	×	×
	% trains delayed more than 9 min	9MIN	×	×	×
	Average delay in minutes	AVMIN	×	×	×
	Average delay of delayed trains	AVMIND	×	×	×
	80th-50th percentile	PERC	×	×	×
	Standard deviation	STDEV	×	×	×
PC characteristics	Population	POP	×	-	-
	Population density	POPDENS	×	-	-
	%<15; %15-20; %20-35; %35-45; %45-65	AGE1520 (etc)	×	-	-
	Share of immigrants	IMMIGRANT	×	-	-
	Share of highly educated population	HIGHEDUC	×	-	-
	Average income per capita	GDP	×	-	-

Data on TTU with respect to both arrival time and departure time were obtained from ProRail, the organization in charge of the management of the rail network infrastructure (ProRail, 2007). This database covers the period between June 2004 and December

2005 and contains data at the train station level on a monthly basis (nineteen months). For each of the 346 stations in the database we have the following information: (i) the number of trains with respectively <3, 3-5, 5-7, 7-9 and >9 minutes of delay on arrival (departure), (ii) the total number of arriving (departing) trains, (iii) the total number of minutes of delay on arrival (departure); the total number of minutes of delay on arrival (departure) for trains which arrive (depart) with more than three minutes of delay. The data is separately available for different parts of the day (morning peak, evening peak or off-peak hours) and different parts of the week (weekends or weekdays).

Based on the available TTU data we derive for each train station the six different TTU indicators introduced in the previous section. The data on 3MIN, 9MIN, AVMIN and AVMIND are directly calculated from the source data. The indicators based on travel time variation, i.e., PERC and STDEV, are estimated based on the available data and a number of assumptions on travel time distributions. For an explanation of the estimation procedure we refer to Annex A. For all indicators, both arrival and departure based specifications are calculated. In order to derive TTU values at the postcode level we calculate for each postcode area the weighted average TTU of the three most frequently used stations in that postcode area, weighted for the relative share of each of these stations.

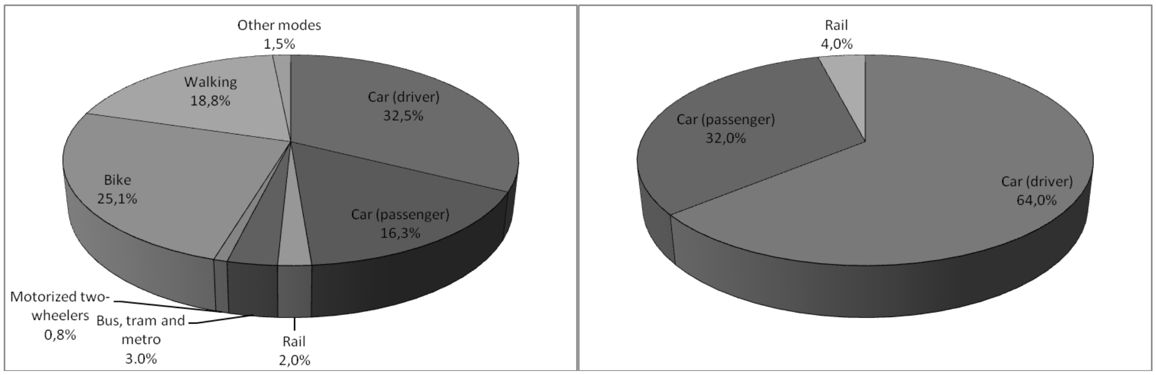
Furthermore, the data set incorporates information on several features related to the railway service, the accessibility of railway stations by various access modes and the TTU, as well as relevant demographic and socio-economic information on the postcode area. At the station level, we have data for the rail network service index[3], availability of Park and Ride facility, and availability of bike stands. Public transport data on frequency and travel time were retrieved from the public transport timetables of the lines linking the postcode area and each of the alternative departure stations. The public transport timetables are available at the 6-digit postcode level – an area comprising up to about 20 houses, and were aggregated to the 4-digit postcode level – an area composed of about seven 6-digit areas. GIS information on the location of the centroid of the postcode area and the railway stations was used to determine the distance measure, which is defined as the distance between the postcode centroid and the station. The car ownership level and the demographic and socio-economic variables were all directly available at the postcode level. Table I gives an overview of explanatory variables used in the anlaysis.

3 DESCRIPTIVE ANALYSES OF CHOICE BEHAVIOUR AND TTU IN THE DUTCH RAILWAYS

(a) (b)

[3] The rail service network index, calculated by Debrezion (2006), is a function of (i) the number of trips attracted to all other stations on the network, (ii) the generalized travel time from the departure station to all other stations on the network (accounting for service frequency, actual travel time and penalties for having to transfer) and (iii) the generalized travel time to distance ratio, which is used to control for the effect of other modes of transport on the attractiveness of rail transport.

Figure 2.a shows that the share of rail trips in the total number of trips made in the Netherlands is only 1.9 percent. This is lower than the share of car trips, but also lower than the share of bike trips and walking trips.



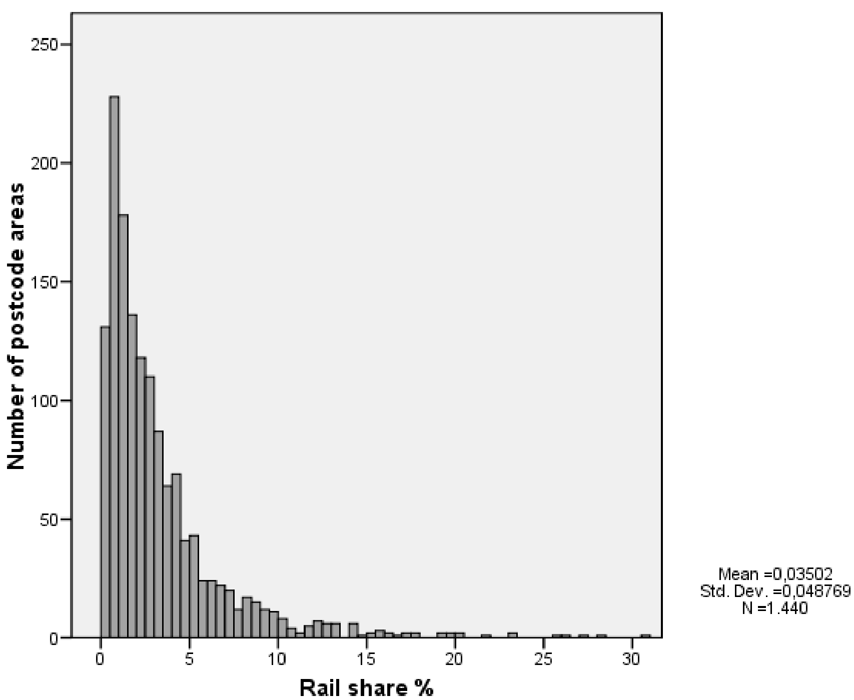
(a) (b)

Figure 2: Modal split of the number of trips in 1440 postcodes in the Netherlands (2005) for all transportation modes (panel a) and when only car and rail are considered (panel b).

For most rail trips, the car is the closest substitute, and often the only viable alternative. Even when focusing on those trips that are made by either rail or car ((a)

(b)

Figure 2.b) the share of rail trips is only 3.7 percent. In the remainder of this study, rail share is defined as the share of rail trips in the total share of trips made by rail and



car.

Figure 3 shows the distribution of the rail share over the 1440 postcode areas included in the analysis.[4] The figure shows that the distribution over postcodes is highly skewed. For the majority of postcodes, the rail share lies below 3 percent. The number of postcodes with rail shares exceeding 10 percent is very low, although some have a rail share of 30 percent or higher.

(a) (b)

Figure 4.a shows the shares of departure from the three stations that attract the most access trips. The share of passengers that depart from the primary station, i.e. the first ranked station in terms of the number of attracted trips, is 86.1 percent. Eleven percent of the passengers depart from the secondary station and 2.9 percent depart from the tertiary station. (a) (b)

Figure 4.b shows the shares of access modes that are used to access the station. The bicycle is the most important access mode with a share of 31.4 percent, followed by public transport with a share of 29.7 percent. Twenty-seven percent of the rail passengers walk to the departure station and only 11.5 percent use the car.

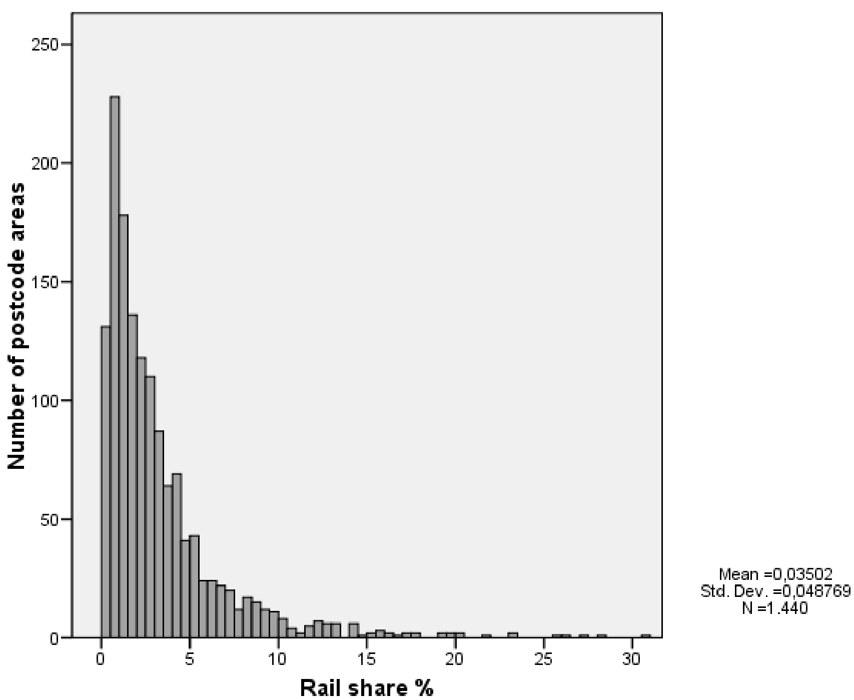
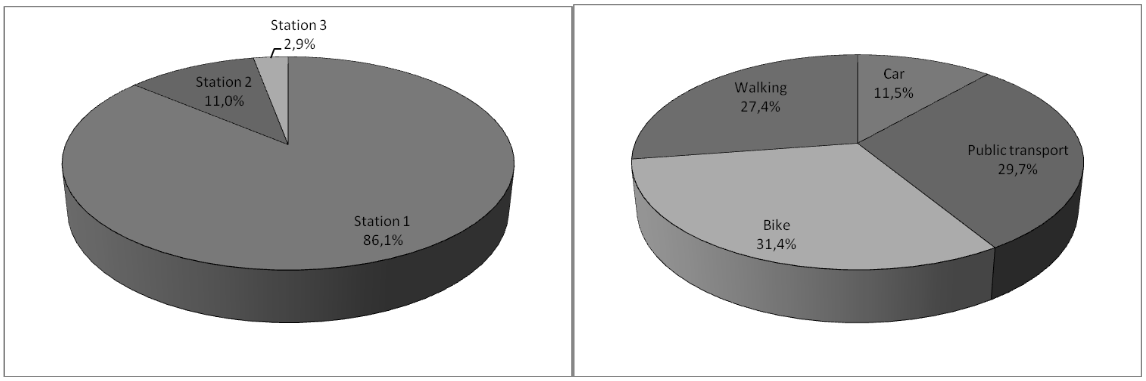


Figure 3: The distribution of rail share over postcodes in the Netherlands

[4]The mean share reported in Figure 4.3 is different from the mean share shown in Figure 4.2. This is because the shares in Figure 4.2 are weighted by the number of trips per postcode.



(a) (b)

Figure 4: Shares of departures from the three stations that attract the most access trips within a postcode (panel a) and modal split of access trips in the Netherlands (panel b)

It is interesting to notice that the relative shares are rather different for access trips to the railway station than for trips in general as shown in Figure 4.2. While the car has the highest overall share, in terms of access trips its share is much lower than that of the other modes. For public transport, on the other hand, the share in access trips is much higher than its overall share. Also for the bicycle and walking modes the shares in access trips are somewhat higher than for trips in general.

4. EMPIRICAL ANALYSIS

This section focuses on the analysis of the impact of TTU on the choice for rail transport, the choice of departure station and the choice of access mode. We carry out the analysis by means of two separate but complementary discrete choice models. First, a binary logit model will be used to analyze the effect of TTU on the choice between rail and car as main transport mode. Next, a 2-level nested logit model in order to simultaneously analyse the impact of TTU on the choice of departure station and access mode.

4.1 The effect of travel time unreliability on the propensity to travel by rail.

The first part of the analysis focuses on the impact of various TTU indicators on the propensity to travel by rail in a postcode area. Following the assumptions of binary logit model we assume that the choice P for train or car is determined by the utility functions V of the two modes, which are expressed as linear functions of the variables listed in Column 1 of
Table I:

$$P(Rail) = \frac{e^{V(Rail)}}{e^{V(Rail)} + e^{V(Car)}}$$
$$V(Rail) = \alpha + \beta_1(TTU) + \beta_2(NETWORK) + ... + \beta_{18}(GDP)$$
$$V(Car) = 0 \quad (1)$$

We estimate this model multiple times, using different TTU indicator or specifications.

4.1.1 Estimation results

The results of the estimation with TTU measured as the percentage of trains with a delay more than three minutes are in Table II. The goodness-of-fit of the model is rather high for both estimations. The adjusted R-square indicates that about 60 percent of the variation in rail shares is explained by the set of explanatory variables included in the model.

As expected, both 3MIN on arrival and on departure have significantly negative effects on the propensity to travel; the higher the percentage of delayed trains in a specific postcode-area, the lower the share of passengers using the train. This suggests that rail use could be improved by decreasing the percentage of delayed trains. The coefficient is higher for 3MIN on departure than for 3MIN on arrival. This may be explained by the fact that the choice of departure station is analyzed at the home-end of the journey. In particular for commuters, but also for most leisure travellers, a punctual departure from the home-end station is important as it increases the probability of a punctual arrival at the activity-end of a journey or a transfer point, and thus reduces the probability of being late for work or missing a connection. On the other hand, a punctual arrival at the station at the home-end of the journey is less important as the traveller is less likely to carry out a scheduled activity or to make a transfer and continue his journey.

The other results from Table II indicate that the share of rail transport is higher if the rail network service is higher, the distance to the station (from the postcode centroid) is smaller, the travel time to the station is shorter and the service frequency of the public transport to the station is higher. Furthermore, the propensity to use rail transport is higher if bike parking facilities are present. The number of cars per household in the postcode negatively affects related to the choice of rail. The Park and Ride facility does not have a significant impact on the rail share. For each of these variables, the estimated coefficients have the expected sign.

Table II: Estimation results of a binary logit analysis of mode choice at the postcode area level, including 3MIN on arrival and on departure as explanatory variables

	(1)		(2)	
(Constant)	-5.086	**	-5.040	**
3MIN on arrival	-0.744	**		
3MIN on departure			-1.015	**
Rail network service level	0.249	**	0.241	**

Distance to station	0.000	**	0.000	**
Public transport travel time	-0.018	**	-0.018	**
Public transport frequency	0.110	**	0.110	**
Guarded bike parking	0.238	**	0.247	**
Park and Ride facility	-0.003		-0.002	
Population (x1000)	-0.003		-0.003	
Population density	0.001		0.001	
% under15	-3.524	**	-3.571	**
% 15-20	10.833	**	10.717	**
% 20-35	2.316	**	2.329	**
% 35-45	4.053	**	4.152	**
% 45-65	-0.145		-0.104	
Share of immigrants	-0.425		-0.439	
% of populated highly educated	1.358	**	1.402	**
Income per capita (x1000 euro)	0.086	**	0.084	**
Cars per household	-0.314	**	-0.320	**
R2-adjusted	0.596		0.598	
N	1440		1440	

** = significant at the 0.01 level
* = significant at the 0.05 level

If we look at the demographic and socio-economic postcode characteristics, we see that population and population density do not significantly affect the share of traveller that choose the train. Age does play a role; the share of rail is very low for the group below 15, high between age 15 and 45 and low again for the group over 45. The share of immigrants in the postcode area does not significantly affect rail use. Both the share of the population which is highly educated and the average income level per capita have a positive effect on the propensity to travel by rail. Except for the insignificant effect of population density, these results are according to expectations.

Table III: Estimation results of binary logit analysis of the choice of rail on the postcode area level, based on a series of models in which TTU-indicators are included separately.

		On arrival			On departure		
		Beta		R2-adj	Beta		R2-adj
Indicator	3MIN	-0.74	**	0.596	-1.01	**	0.598
	9MIN	-2.39		0.595	-4.61	**	0.598
	AVMIN	0.02		0.594	0.02		0.594
	AVMIND	-0.01		0.595	-0.02	*	0.595
	PERC	-0.08		0.595	-0.19	**	0.600
	STDEV	-0.11	**	0.598	-0.16	**	0.604

** = significant at the 0.01 level
* = significant at the 0.05 level

Model (1) is estimated twelve times, each time including a different TTU-indicator, either on arrival or departure. Table III shows the coefficient and goodness-of-fit measure for each indicator.[5] All indicator have a negative impact on rail share (both on arrival and departure), except for the indicator based on the average delay in minutes. The coefficient of the latter indicator is not statistically significant, though.

All departure-based indicators except AVMIN enter significantly, whereas of the arrival-based indicators only 3MIN and STDEV have significant coefficients. Furthermore, the absolute values of the estimated coefficients for TTU on departure are higher than on arrival, indicating again the relative importance of departure from the home-end of the journey. This is emphasized by the higher R-squares for the models that include departure-based indicators. The R-squares indicate that the model based on STDEV on departure offers the best statistical explanation for the differences in rail share. This indicates that the unreliability experience of the customers is best captured by using STDEV as a measure of TTU.[6]

4.1.2 Analysis of impact

While the signs of the estimated coefficients in Table III indicate the direction of the impact of TTU on rail share, the coefficients themselves are not directly comparable in terms of the magnitude of the impact. In order to compare the impact of TTU-indicators we calculated the percentual and absolute increase in rail trips per person per year in the Netherlands as a result of a 10 percent improvement in TTU. Based on the results in Table III, we focused only on departure-based TTU-indicators.

The results in Table IV show that a ten percent improvement in 3MIN on departure leads to an increase in the number of rail trips with 1.42 percent. Based on the average number of rail trips before the improvement of 22.6 trips per person per year, this translates into an increase of 0.32 rail trips per person per year. Improvements in

[5] The estimated coefficients for the other explanatory variables included in the model are not displayed in order to save space. Note that the estimated values for these coefficient differ only marginally from the corresponding values in Table 5.1.

[6] Some caution should be taken when interpreting the coefficients in Table 5.2. Due to statistical correlation among TTU-indicators, the coefficient of a specific indicator does not only capture the effect of that indicator on the propensity to travel by rail but also, indirectly, part of the effects of the other TTU-indicators. In order to obtain coefficients that accurately capture the impact of a specific TTU-indicator, maintaining ceteris paribus conditions, the TTU-indicators should be included simultaneously in the model, i.e., an 'inclusive' model should be estimated. Unfortunately, statistical correlation among indicators is likely to result in multicollinearity in the regression result. This is evident from the estimation results of such an 'inclusive' model that we estimated for both TTU on arrival and on departure. While the coefficients of 3MIN, 9MIN and STDEV have the expected sign and, in the case of 3MIN and STDEV, are significant, the coefficients of AVMIN, AVMIND and PERC are positive, suggesting that increasing these aspects of TTU results in a higher probability of choosing the train, which, from a theoretical point of view, is a very implausible result. Various stepwise regression approaches based on excluding variables with an insignificant or positive coefficient, invariably result in STDEV remaining as the only significant variable. The latter result confirms our conclusion in that STDEV captures best the rail passengers' perception of TTU. Due to the multicollinearity issue and our interest in a comparative analysis, we proceed with our initial approach of including TTU-indicators separately. In doing so, we take into account the limitations with respect to the interpretation of the estimated coefficients. Our interpretation henceforward is that the statistical impact of a variable indicates the degree to which the associated TTU-indicator serves as an approximation of the unobserved rail passengers' true perception of TTU, as revealed by actual travel behaviour.

9MIN or AVMIND on departure result in lower increases in rail trips (1.25 and 1.32 percent, respectively). The impact of improvements of the travel time variation is much higher than that of the other indicators. A ten percent improvement of PERC leads to an increase in the rail share by 3.61 percent, or 0.82 rail trips per person per year. An equal improvement of STDEV results in an increase in rail share by 4.22 percent, which translates into an increase of 1.05 rail trips per person year. This result corroborates the findings of Section 4.1.1 that STDEV best captures the customers' perception of TTU.

Table IV: Impact of a 10 percent improvement in different TTU-indicators on the percentual change in rail share and the increase in the number of rail trips per person per year

	TTU on departure	
	%	Trips pp
3MIN	1.42%	0.32
9MIN	1.25%	0.28
AVMIN	-0.20%	-0.05
AVMIND	1.32%	0.30
PERC	3.61%	0.82
STDEV	4.63%	1.05

4.2 The effect of TTU on the choice of access mode and route choice

Given that the passengers in our analysis have already decided to travel by train, they face two interrelated choices: (i) the choice of the departure station and (ii) the choice of access mode used to reach the departure station. We assume that these two choices are made simultaneously, in the sense that travellers choose a combination of access mode and departure station. This section focuses on the impact of different TTU-indicators on those two choices.

The simultaneous choice is modelled by a 2-level nested logit model, to account for the fact that choice alternatives that have the same access mode are more similar than choice alternatives that have different access modes. The structure for this model is depicted in**Error! Reference source not found.**. There are twelve alternatives j and four nests corresponding to four access modes N1, N2,…,N4. Suppose, $y \in \{1, 2, ..., j, ...12\}$ is an indicator for the realized outcome. If alternative j is an element of nest Nk, then the probability of y = j can in general be decomposed into: $P(y = j) = P(y \in N_k) \cdot P(y = j \mid y \in N_k)$

Travellers are assumed to choose the alternative from which they derive the highest utility. The utility of each alternative j, i.e. combination of an access mode and station, are expressed as linear functions of the variables listed in Column 2 and 3 of Table I, in the following fashion:

$$V(CAR \cap S_i) = \alpha_{car} + \beta_{TTU}(TTU_i) + \beta_{net}(NET_i) + \beta_{dist}^{car}(DIST_i) + \beta_{cars}^{car}(CARS) + \beta_{park}(PARK_i)$$
$$V(PT \cap S_i) = \alpha_{PT} + \beta_{TTU}(TTU_i) + \beta_{net}(NET_i) + \beta_{dist}^{PT}(DIST_i) + \beta_{cars}^{PT}(CARS) + \beta_{freq}(FREQ_i) + \beta_{TT}(TT_i)$$
$$V(BIKE \cap S_i) = \alpha_{bike} + \beta_{TTU}(TTU_i) + \beta_{net}(NET_i) + \beta_{dist}^{bike}(DIST_i) + \beta_{cars}^{bike}(CARS) + \beta_{bpark}(BPARK_i)$$
$$V(WALK \cap S_i) = \beta_{TTU}(TTU_i) + \beta_{net}(NET_i) + \beta_{dist}^{walk}(DIST_i)$$

(2)

If the error terms (not shown in the utility specifications) are assumed to be distributed according to a special form of the generalized extreme value (GEV) distribution, the resulting outcome probabilities are:

$$\frac{e^{\frac{1}{\tau_k}V_l}}{e^{IV_j}} \cdot \frac{e^{\tau_k IV_k}}{\sum_m e^{\tau_m IV_m}}$$

With the inclusive value IVk defined as

$$IV_k = \ln \sum_{l \in N_k} e^{\frac{1}{\tau_k}V_l}$$

The parameters τ_k are called IV or dissimilarity parameters. They correspond to the degree of dissimilarity between the alternatives within one nest.

4.2.1 Estimation results

We first estimate the model with 3MIN indicator, both on arrival and on departure. The results are shown in Table V. The R-square indicates that about 25 percent of the variation in rail shares is explained by the set of explanatory variables included in the model. Both 3MIN on arrival and 3MIN on departure have negative coefficients, but the impact of 3MIN on arrival is lower and, moreover, not statistically significant. As discussed in Section 4.1 with respect to the impact on rail share, this may be linked to the fact that TTU is measured at the home-end of the rail trip where a punctual departure may correspond to a punctual arrival at the activity-end of the journey. Based on this result and the findings in Section 4.1, the remainder of the study focuses exclusively on TTU on departure.

The level of the rail network service of a railway station has a positive effect on the probability of choosing it as departure station. The distance from the postcode centroid to the railway station affects the probability of choosing that station negatively, regardless of which access mode is used. However, the impact is stronger on the choice of walking or using bike to reach the station than on the choice of getting there by car or public transport.

Table V: Estimation results of a nested logit analysis of the choice of departure station and access mode

	TTU on arrival		TTU on departure	
Constant for car	-3.80	**	-3.78	**
Constant for public transport	-0.86	*	-0.83	

Constant for bike	-1.09	**	-1.07	**
3MIN on arrival	-0.48			
3MIN on departure			-1.73	**
Rail network service index	1.07	**	1.09	**
Distance: car choice	-0.11	**	-0.11	**
Distance: bike choice	-0.48	**	-0.49	**
Distance: public transport choice	-0.05	**	-0.05	**
Distance : walking choice	-1.12	**	-1.12	**
Car ownership: car choice	0.75		0.72	
Car ownership: public transport choice	-4.25	**	-4.28	**
Car ownership: bike choice	0.34		0.33	
Park and Ride facility: car choice	0.93	**	0.93	**
PT service frequency: public transport choice	0.11	**	0.10	**
PT travel time: public transport choice	-0.01	*	-0.01	*
Availability of bike: bike choice	0.38	**	0.36	**
R2-adjusted	0.247		0.249	

** = significant at the 0.01 level
* = significant at the 0.05 level

Car ownership has a negative effect on the choice of public transport as access mode, but does not have a significant effect on the choice of any of the other access modes. The availability of Park and Ride or bike parking facilities has a positive impact on the choice of car and bike, respectively. Finally, the probability of using public transport to reach the station is increased by the public transport service frequency and decreased by the public transport travel time to the station.

We estimate model (2) twelve times, each time including a different TTU-indicator, either on arrival or departure. Table VI shows the estimated coefficients for the TTU indicators.

Table VI: Estimation results for various indicators of TTU on departure

		Estimation results		
		Beta		R2-adj
Indicator	3MIN	-1.73	**	0.253
	9MIN	-6.06	**	0.252
	AVMIN	-0.05		0.251
	AVMIND	0.01		0.251
	PERC	-0.21	**	0.252
	STDEV	-0.14	**	0.253

** = significant at the 0.01 level
* = significant at the 0.05 level

The results show that the TTU-indicators based on punctuality (3MIN and 9MIN) and travel time variation (PERC and STDEV) have a significantly negative impact on the probability that the station in question is chosen. The coefficients for the indicators based on the size of the delay (AVMIN and AVMIND) are not significant. Apart from the coefficient of AVMIND, the pattern of significance matches the pattern in Table IV, with respect to the impact of TTU on departure on rail choice. The goodness-of-fit is highest for 3MIN and STDEV, suggesting that these two indicators capture best the TTU perception of rail passengers.

4.2.2 Analysis of impact

In this section we analyze the impact of improving the TTU at the station with the highest share. We calculate the impact on the choice of departure station and the choice of access mode and show the percentual change in the share as well as the change in the number of trips per person per year. The results with respect to the choice of departure station are in Table VII.

The table shows that a ten percent improvement in 3MIN on departure at primary railway stations leads to a 0.42 percent increase in the share of departures from those stations. The ranking in the (significant) TTU-indicators, according to their impact on station choice, is the same as the ranking according to their impact on rail choice in Table III. The indicators based on travel time variation have the biggest impact, with improvements in STDEV and PERC leading to percentual increases in the share of the primary station of 0.59 and a 0.67 percent, respectively. These are followed by 3MIN and 9MIN.

Table VII: The impact of a ten percent improvement in various TTU-indicators at primary stations on the choice of departure station

		Change in departure station choice	
		%	Trips p.p. per year
3MIN	Primary station	0.42%	0.081
	Secondary station	-2.59%	-0.064
	Tertiary station	-2.57%	-0.017
9MIN	Primary station	0.28%	0.054
	Secondary station	-1.73%	-0.043
	Tertiary station	-1.71%	-0.011
AVMIN	Primary station	0.13%	0.025
	Secondary station	-0.78%	-0.019
	Tertiary station	-0.78%	-0.005
AVMIND	Primary station	-0.12%	-0.024
	Secondary station	0.76%	0.019
	Tertiary station	0.74%	0.005
PERC	Primary station	0.59%	0.114
	Secondary station	-3.63%	-0.090

	Tertiary station	-3.59%	-0.024
STDEV	Primary station	0.67%	0.131
	Secondary station	-4.17%	-0.104
	Tertiary station	-4.11%	-0.027

Table VIII, which displays the expected impact of improving TTU on departure on the access mode shares, shows the same ranking in the (significant) TTU-indicators. The table furthermore shows that for all significant indicators of TTU on departure, an increase in TTU leads to a shift toward the use of public transport. An improvement in STDEV results in an increase in the share of public transport of 0.38 percent. The increase for PERC, 3MIN and 9MIN is 0.32, 0.20 and 0.16 percent, respectively. There is also a shift towards the use of car as an access mode, but this effect is lower than that for public transport. The shift toward public transport and car is mainly caused by a shift away from walking as an access mode. The share of bicycle is unaffected by the improvement in TTU.

Table VIII: The impact of a ten percent improvement in various TTU-indicators at primary stations on the choice of access mode

		Change in access mode choice	
		%	Trips per person per year
3MIN	Car	0.13%	0.003
	Public transport	0.20%	0.014
	Bike	0.00%	0.000
	Walking	-0.28%	-0.017
9MIN	Car	0.09%	0.002

	Public transport	0.16%	0.010
	Bike	0.00%	-0.000
	Walking	-0.21%	-0.013
AVMIN	Car	0.04%	0.001
	Public transport	0.07%	0.005
	Bike	-0.01%	-0.000
	Walking	-0.09%	-0.005
AVMIND	Car	-0.04%	-0.001
	Public transport	-0.07%	-0.005
	Bike	0.00%	-0.000
	Walking	0.10%	0.006
PERC	Car	0.19%	0.005
	Public transport	0.32%	0.021
	Bike	-0.02%	-0.001
	Walking	-0.40%	-0.025
STDEV	Car	0.23%	0.006
	Public transport	0.38%	0.025
	Bike	-0.02%	-0.001
	Walking	-0.49%	-0.030

4.3 Analysis of total impact

In this section we will analyze the impact of a ten percent improvement in TTU at the primary station of each postcode area on rail choice and access mode choice simultaneously. We focus on the change in the total number of rail trips, the total number of trips with each access mode and the total number of trips from each of the three categories of departure stations in the Netherlands. The results are shown in Table IX. The first column shows the total number of rail trips, the trips per access mode and the trips per station before any improvements in TTU. The other columns each show the change in these values following a ten percent improvement in the corresponding TTU-indicators

Table IX: The impact of a ten percent improvement in various indicators of TTU on departure at primary stations on the annual rail trips, access trips for various access modes and access trips to each of the departure stations

	Before improvement	Change following the improvement					
		3MIN*	9MIN*	AVMIN	AVMIND	PERC*	STDEV*
Rail trips	210,552,446	2,430,839	2,141,803	-343,229	2,254,947	6,173,174	7,913,009
Car	24,226,984	310,915	268,673	-30,398	248,892	757,416	967,430
Public transport	62,549,120	850,955	734,909	-57,001	622,908	2,039,825	2,597,102
Bike	66,167,626	764,978	671,856	-111,917	708,603	1,926,793	2,473,786

Walking	57,608,715	503,992	466,365	-143,912	674,545	1,449,141	1,874,693
Primary station	181,256,921	2,859,847	2,354,786	-67,015	1,718,602	6,407,695	8,076,729
Secondary station	23,114,623	-339,444	-169,060	-218,309	424,016	-187,049	-132,117
Tertiary station	6,180,901	-89,563	-43,922	-57,903	112,330	-47,472	-31,602

* Indicators for which the calculations are only based on statistically significant coefficient estimates.

The first row shows the change in the total number of rail trips. The results show again that STDEV has the highest impact on the total number of rail trips; improving STDEV by ten percent leads to an increase in the total number of rail trips per year of nearly 8 million. For PERC the increase is almost 6.5 million while for the two indicators based on punctuality, the total increase is much lower. This confirms the conclusion in Section 4.1 that STDEV seems to be the best proxy for the rail passengers' perception of TTU.

Rows 2-5 show how the increase in the number of rail trips can be broken down according to access mode. For the significant TTU-indicators, the increase in the number of rail trips (the 'new' rail trips), consists for about 35 percent of rail trips for which public transport is used as the access mode. This is slightly higher than the 'base share' of public transport, i.e., the share in the total number of rail trips before the improvement in TTU. This means that the share of public transport is increasing. The same holds for the car, which has a share of about 12 percent in the new access trips. The share of walking as access modes in the new rail trips is about 22 percent which is lower than the share in the total number of access trips. This indicates that the shift towards public transport, following an improvement in TTU, corresponds to a shift away from walking as an access mode.

Rows 6-8 of Table IX show how the increase in the number of rail trips can be broken down according to the departure station used for the access trip. The increase by more than 8 million in the number of annual rail trips departing from primary stations, resulting form a 10 percent increase in STDEV on the primary station, exceeds the increase in the total number of rail trips. This means that, despite the increase in rail trips, the number of rail trips departing from secondary and tertiary stations actually decreases. Apparently, the improvement on the primary stations attracts the majority of the new rail passengers as well as some of the rail passengers who currently use one of the other railway stations in the postcode as departure stations.

5. CONCLUSION AND POLICY IMPLICATIONS

This study focuses on the impact of travel time unreliability (TTU) on travel behaviour among railway passengers in The Netherlands. First, we discussed how travel time unreliability is measured by the Dutch Railways and provided some points of critique on this measure, including the exclusive focus on TTU on arrival, the exclusive focus on delays rather than early arrivals and departures and the negligence of travel time variation and the size of the delay. We introduced six different TTU-indicators, two based on the probability of a delay, two based on the size of delay in minutes, and two based on the variation in the travel times. After a descriptive statistical analysis we carried out a discrete choice analysis in which we compare the impact of the TTU-indicators on the choice to travel by train, the choice of access mode to reach the railway station and the choice of departure station.

A general conclusion from the results of the discrete choice analyses is that departure-based TTU-indicators were found to have a higher impact on travel behaviour than their arrival-based counterparts. This conclusion holds with respect to explaining the mode choice as well as the departure station choice and the access mode choice. A possible reason for this is that we measure TTU on the home-end of the journey. A punctual departure from the home-end increases the likelihood of a punctual arrival at the activity end of the journey, which for the individuals in our database is probably more important than a punctual arrival at the home-end of the journey after the return trip.

A second general conclusion is that for all three choice levels considered, indicators based on travel time variation (PERC and STDEV), were found to have the largest impact and provide the best model fit; indicators based on punctuality (3MIN and 9MIN) were found to be 3rd and 4th, respectively, in terms of their impact and model fit; the two indicators based on the size of the delay (AVMIN and AVMIND) were found to have the smallest impact and to provide the worst model fit. A ten percent improvement in STDEV results in an increase by almost 8 million rail trips per year in The Netherlands, while a ten percent improvement in the 3MIN indicator results in an increase by only 2.5 million trips per year. Furthermore, a 10 percent improvement in STDEV leads to an increase in the share of the primary station in the postcode by 0.67 percent and to an increase in the use of public transport for station access by 0.38 percent. An equivalent improvement in 3MIN results in increases of only 0.42 percent and 0.20 percent, respectively.

The general pattern that can be derived from these results is that for the rail passenger the size of the delay as such is not very important. More important is that the train arrives and departs in time and especially that the variation in arrival and departure time is low, i.e., arrival and departure time are relatively predictable. This suggests that the exclusive focus on delays is indeed a drawback of the indicator used by the Dutch Railways. The fact that the impact of STDEV is higher than that of PERC indicates furthermore that the traveller gives a higher weight to large deviations from the mean arrival or departure time. This indicates that trains that arrive or depart much later or earlier than normal have a relatively large effect on the travellers' perception of unreliability, perhaps because such events are associated with a relatively large number of missed connections, in particular in the case of late arrivals and early departures. An explanation would be that more extreme events are remembered better.

Based on these results one may conclude that STDEV is a better approximation of the rail passengers perception of TTU than 3MIN, the measure that is used by the Dutch Railways and that, in order to increase the rail share, attention should be focused on decreasing the standard deviation of the travel times and that the Dutch Railways should be evaluated based on travel time variation rather than punctuality. However, it should be taken into consideration that the present study has not incorporated the cost aspect in the analysis. This means that the study does not provide a comparative analysis of cost-efficiency of improvements in the various TTU-indicators. While a ten percent improvement in STDEV has a larger impact on rail trip than a ten percent improvement in 3MIN, it may also be a more costly option. The fact that 3MIN and 9MIN may be significantly improved by adjustments in the time tables only, without any changes in realized travel times, may serve to demonstrate this issue. Bearing this in mind, we conclude that out of the TTU-indicators included in the analysis, the standard deviation of travel times serves best as an approximation of the unreliability experience of the rail passenger. As such, it may indeed be more useful to measure TTU by means of travel time variation rather than punctuality. With respect to improving reliability, a useful approach might be a multi-criteria decision analysis, which compares a number of alternative strategies aimed at improving TTU, taking into account both the investment costs of each alternative and the degree to which it leads to an improvement in STDEV.

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ANNEX A: CALCULATION OF STANDARD DEVIATION AND 80TH MINUS 50TH PERCENTILE

As discussed in Section 2 we have the following data available with respect to TTU:

- Number of trains with {< 3; 3-5; 5-7; 7-9;>9} minutes of delay on arrival (departure)
- Total number of arriving (departing) trains
- Total number of minutes of delay on arrival (departure)
- Total number of minutes of delay on arrival (departure) for trains which arrive (depart) with more than three minutes of delay.

First, we assume that the distribution of arrival and departure times are uniform within each of the five categories of delay. Standard deviation and percentiles can then be calculated based on the middle point of the intervals.
With respect to the three intermediate intervals the middle points are known. However, since the first interval's lower limit and the last interval's upper limit not known, the middle points can not be readily calculated. The middle point of the last interval can be estimated according to the following equation:

$$\bar{X}^L = \sum_{i=2}^{5} M_i N_i \Leftrightarrow M_5 = \frac{\bar{X}^L - \sum_{i=2}^{4} M_i N_i}{N_5}$$

Where $\bar{X}^L$ represents the mean delay in minutes for delayed trains, Mi represents the middle point of interval i, Ni represents the number of trains in category i and $\bar{X}$ represents the average delay in minutes. Next, the middle point of the first interval can be calculated as follows:

$$\bar{X} = \sum_{i=1}^{5} M_i N_i \Leftrightarrow M_1 = \frac{\bar{X} - \sum_{i=2}^{5} M_i N_i}{N_1}$$

Based on the estimated and calculated middle points, the standard deviation can be computed as follows:

$$SD = \sqrt{\frac{\sum_{i=1}^{5}\left(M_i - \bar{X}\right)^2 N_i}{\sum_{i=1}^{5} N_i - 1}}$$

The 50th and 80th percentile can be calculated as follows:

$$P^{PERC} = \left(M_1 - \frac{1}{2}R_1\right) + \sum_{i=1}^{k-1} R_i + \frac{\left(PERC - \sum_{i=1}^{k-1} S_i\right)}{S_K} R_k$$

where PERC denotes the percentile to be calculated, Ri represents the bandwidth of interval i, k represents the interval within which the percentile is located and Si represents the percentage of trains in interval i.