VALUATION OF UNCERTAINTY IN TRAVEL TIME AND ARRIVAL TIME: SOME FINDINGS FROM A CHOICE EXPERIMENT

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Abstract

In this paper we investigate the influences of different specifications of scheduling components taking into account the uncertainty in travel time and arrival time. We also look at the departure side scheduling components and take into account acceptability bandwidths for departure and arrival times. We found that specifications based on the earliest arrival time are the most plausible but that the different models are difficult to compare because of scaling issues involved in the different specifications of attributes.

Keywords: departure time choice, travel time uncertainty, schedule delays

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1 Introduction

Road pricing is considered as one of the transportation strategies to improve efficiency of the use of the transportation resources or to finance infrastructure. Road pricing means that motorists pay directly for using a particular roadway or driving in a particular area. In that way, road pricing may directly benefit motorists through reduced congestion or improved roadways. On the other hand, motorists may also have to pay a toll for an uncongested trip. Consequently, the trade-off between benefits and costs should be made, not only for the individual drivers, but also for the transportation system as a whole.

Our objective is to look at road pricing from a transportation perspective and thus to develop tools and models that can produce 'trusted' forecasts of network effects of different road pricing measures. These network effects are in fact the summed results of changes in individual choice behavior. Therefore, in order to determine network effects we need detailed information about individual choice behavior, taking into account the heterogeneity of travelers. The network conditions are calculated using a route choice and traffic assignment model. Since the traffic model has to correctly forecast the travel times and other relevant trip attributes in different periods, a dynamic traffic assignment model is needed, which should be able to cope with multiple user classes.

Summarizing this we need two components to forecast the effects of road pricing measures:

1. behavioral models that describe the responses of individuals subject to various forms of road pricing;
2. a dynamic traffic assignment model to determine traffic conditions resulting from these responses.

In this paper we focus on the first component, namely the development of the necessary behavioral models. For research on the development of the corresponding dynamic traffic assignment models we refer to (Joksimovic, et.al. 2004). In this paper we first present what data were collected for estimating the choice models (Section 2). In Section 3 and Section 4 we present the general modeling approach and discuss different model results. In the experiment we introduced uncertainty in travel time, which also implies uncertainty in arrival time. As a result the travel time and arrival time taken into account in the decision-making of respondents is unknown to us. This introduces possibilities for different specifications of travel time and scheduling attributes which we will investigate in this paper. We will look at route, departure time and mode choices. In order to analyze these choices a stated choice experiment was constructed in which respondents distributed 10 trips between four alternatives (three car and a public transportation alternative). Using the data from the experiment we estimated choice models following the schedule delay framework from Vickrey, 1969 and Small, 1987, assigning penalties to shifts from the preferred time of travel to earlier or later times.

2 Stated choice experiment

The aim of the experiment is to find the trade-offs commuters make between paying a road pricing fee and optimizing their travel conditions in terms of departure time, reliability of travel time, route length and mode. We assume that after the introduction of a road pricing measure people will change their travel behaviour depending on available choice alternatives. Route, departure time and mode adjustments were found to be important in some implemented road pricing measures: see (Van Amelsfort, et.al., 2003) and (Gomez-Ibanez and Small, 1994). Particularly the departure time adjustments are of interest to us.

We investigate home-to-work trips of commuters who travel to work by car at least three days a week and who endure delays of at least 10 minutes. Capturing a very accurate mode choice is of less interest to us; mode choice is included as an escape from using the car (while still being able to get to work). We offer each respondent four alternatives in one choice set to make sure that respondents have these trade-offs available in each choice situation. Each alternative is discussed in detail later in this section.

We based the choice alternative in our experiment as much as possible on actual choice behavior of the respondent. This means we asked respondents questions about their current average travel conditions, characteristics of available non-chosen alternatives (routes and modes), questions about their time constraints at departure and arrival side of their trip and the preferred travel conditions in case respondents would be certain that there is no congestion. The levels of the attributes in the experiment are all based on the self reported characteristics of their current choices and choice environment. We also recorded different socio-economic characteristics of the respondents.

In this section we discuss the setup of the choice experiment. We present the different alternatives available in each choice set and the attributes they are comprised of. Furthermore we discuss how the attribute levels are calculated based on current trip characteristics.

2.1 Choice alternatives presented in the experiment

Respondents are presented 11 choice sets. Each choice set contains the same number and type of alternatives as presented in Table 2.1. The alternatives are presented in four columns while in the rows the different attributes with specific levels are presented. In the bottom row the respondent can enter the number of times they would choose this alternatives with a total of 10 trips over all alternatives.

Table 2.1: Overview of choice set

Alternative A	**Alternative B**	**Alternative C**	**Alternative D**
Mode: car **Trip length: x km**	**Mode: car** **Trip length: x km**	**Mode: car** **Trip length: x km**	**Mode: public transport** **Trip length: x km**
Total travel costs: Fuel costs: Charge:	**Total travel costs:** Fuel costs: Charge:	**Total travel costs:** Fuel costs: Charge:	**Total travel costs:**
Departure time:	**Departure time:**	**Departure time:**	**Departure time:**
Travel time between … and … min	**Travel time between … and … min**	**Travel time between … and … min**	**Travel time:**
of which free-flow:...min min.congestion:… min max.congestion:....min	of which free-flow:...min min.congestion:… min max.congestion:....min	of which free-flow:...min min.congestion:… min max.congestion:....min	
Arrival time between …. and ….	**Arrival time between …. and ….**	**Arrival time between …. and ….**	**Arrival time:**
Number of trips:	**Number of trips:**	**Number of trips:**	**Number of trips:**

Alternative A: paying for preferred travel conditions, is based on the reported preferred travel conditions; this includes the preferred arrival time and the non-congested travel time. Small deviations are created on these preferred travel conditions. The price in alternative A is relatively high.

Alternative B: adjust arrival time and pay less, has a lower road pricing fee than alternative A, but in return the travel conditions are less attractive. There will be more congestion which leads to higher travel times and travel time uncertainty. Both departing earlier and later are included in this alternative.

Alternative C: adjust arrival time and route and pay less, also has less favorable traffic conditions are than alternative A. In this case respondents are provided with a detour to pay less (or avoid paying), but in return they will face longer times which are also more congested than in alternative A. The arrival time changes are smaller than in alternative B.

2.1.1 Alternative D: adjust mode to avoid paying charge

In alternative D respondents are provided with an alternative mode compared to using the car. This option is always a public transport option even though currently there might not be a public transport option available to the commuter. To reduce the complexity of the experiment we choose to only include mode shifts to public transportation. In many cases the travel distances are too large for the bicycle to be a reasonable alternative and carpooling is less interesting to us.

2.2 Attributes and levels used in the experiment

Travel time

Travel time is calculated the same way for alternatives A, B and C, only the attribute levels differ among the alternatives. The travel time used in the experiment is based on the reported (by the respondent) free-flow travel time for the home-to-work trip, as is the trip length. For the congested travel time we assume a speed that is one third of the free-flow speed. Adding the free-flow travel time and the congested travel time makes the total travel time for the trip.

$$\bar{\tau}^i_{al} = \frac{\alpha_{al}}{\hat{\bar{\tau}}^i}$$

$$\tilde{\tau}^i_{al} = \frac{1-\alpha_{al}}{3\hat{\bar{\tau}}^i}$$

$\alpha_{a,l}$ = multiplication factor : trip length in free - flow conditions for alternative a, for level l

$\bar{\tau}^i_{al}$ = free - flow travel time for respondent i, alternative a, for level l

$\tilde{\tau}^i_{al}$ = congested travel time for respondent i, alternative a, for level l

$\hat{\bar{\tau}}^i$ = reported free - flow travel time by respondent i

This approach ensures that the resulting travel times and its two components are consistent with reality and that we can distinguish two components of travel time. For alternative A the free-flow part of the trip is higher (levels: $\alpha_{a,l}$ = 0.85,0.9,0.95,1.0) than for alternative B (levels: $\alpha_{b,l}$ = 0.65,0.7,0.75,0.8) while the free-flow part of the trip is higher for alternative B than for alternative C (levels: $\alpha_{c,l}$ = 0.55,0.6,0.65,0.7).

Arrival time

The arrival times in the experiment are based on the reported preferred arrival time which is the arrival time in case the trip would be guaranteed without congestion, while home and work constraints do not change. In alternative A, the arrival times have small deviations from the preferred arrival time (levels -10,-5,0,5 minutes from preferred arrival time). In alternative B these deviations are much bigger (levels -50,-30,-10,10 minutes from preferred arrival time). Alternative C (levels -30,-20,-10,10 minutes from preferred arrival time) and D (levels -30,-10,10,30 minutes from preferred arrival time) have intermediate levels compared to alternatives A and B.

Uncertainty of travel time

As a base for uncertainty of travel time we use the difference between reported average travel time (including congestion) and the reported free-flow travel time (without congestion). We assume that this value is a reasonable indicator for the experienced variability in travel time for that respondent. We are not trying to model uncertainty as a result of incidents, but only because of natural variation in travel times due to congestion. Using this value we calculate an uncertainty bandwidth (a factor of the calculated difference). To respondents we provide information that they arrive between x and x + uncertainty, with equal chance of occurrence of any arrival time in the interval because of the uncertain occurrence of congestion.

$$\omega_{al}^{i} = \beta_{al}(\hat{\tilde{\tau}}^{i} - \hat{\bar{\tau}}^{i})$$

ω_{al}^{i} = uncertainty in travel time for respondent i, alternative a, for level l

β_{al} = multiplication factor of uncertainty for alternative a, for level l

$\hat{\tilde{\tau}}^{i}$ = reported congested travel time by respondent i

$\hat{\bar{\tau}}^{i}$ = reported free-flow travel time by respondent i

Since alternative A has the preferred travel conditions, the uncertainty factors were small (levels β_{al} = 0.2,0.4,0.6,0.8), for alternative B (levels β_{bl} = 0.8,1.0,1.2,1.4) and C (levels β_{cl} = 0.6,0.8,1.0,1.2) the factors were larger. For alternative D (the public transportation alternative) we assumed the uncertainty of travel time to be zero.

Trip length (for alternative C only)

Alternative C is a route alternative in which we present respondents with an option to avoid paying by taking a detour. This means that the distance of this trip is always longer than for alternatives A and B. The trip length attribute of alternative C has only two levels which contain the multiplication factor of the reported actual trip length (levels 1.2, 1.4).

Road pricing fee

We include the road pricing fee in the experiment as a distance based fee. This is partly because of the policy relevance it has in the Netherlands. The levels of road pricing fees we included are also based somewhat on prices mentioned in Dutch road pricing proposals. Alternative A has the highest prices (levels 8,10,12,14 ct/km) but the best conditions. Alternative B has lower prices (levels 3,4,5,6 ct/km) and alternative C has the lowest prices (levels 0,1,2,3 ct/km).

Travel time in public transportation (for alternative D only)

The travel time of the public transportation alternative is calculated in a different way. It is either based on the reported travel time using public transportation or the free-flow travel time by car. If respondents are unsure about the travel time by public transportation or do not know it at all, we use the free-flow travel time by car multiplied by 1.3. By using this multiplication factor we reflect that travel time by public transportation usually is longer than travel time by car (without congestion). The levels of travel time are again multiplication factors (levels 1.0, 1.2).

2.3 Experimental design

As discussed in the previous section the experiment contains 13 attributes with four levels and 2 attributes with 2 levels. An orthogonal design was constructed to estimate the main effects, which resulted in a design of 44 treatments. A blocking strategy with 4 blocks of 11 treatments was adopted to reduce the number of treatments for each respondent. Respondent were assigned randomly to one of the blocks in the design. The treatments in each block were also presented to respondents in a randomized order.

3 General modeling approach

Using the data from the experiment we estimated choice models following the schedule delay framework from Vickrey, 1969 and Small, 1987, by assigning penalties to shifts from the preferred time of travel to earlier or later times as shown in Figure 3.1.

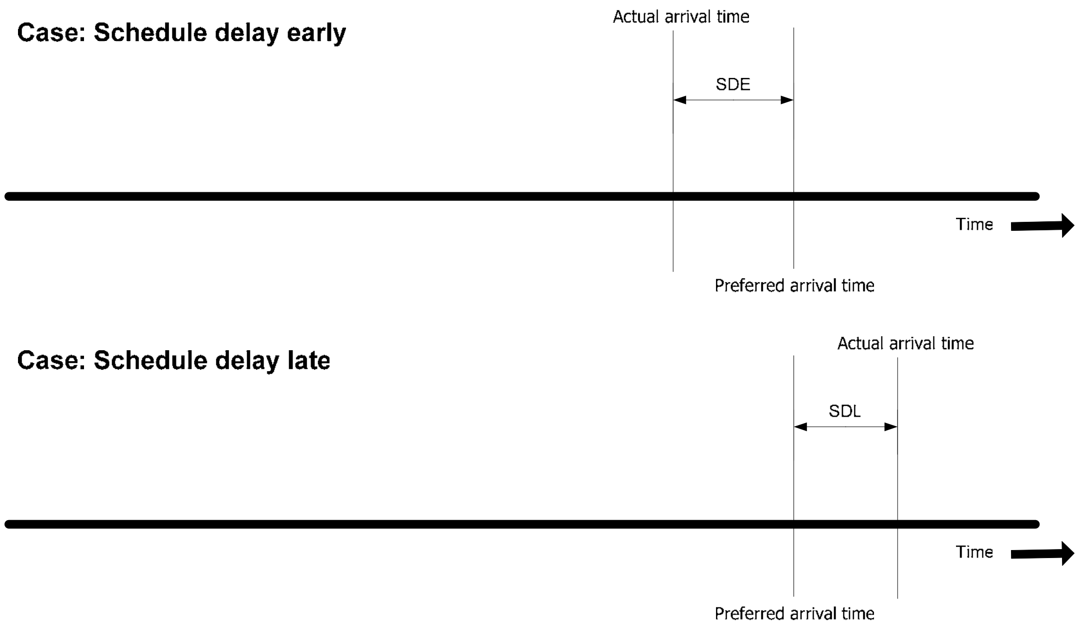


Figure 3.1: Scheduling delay early and late

Our main objective is to investigate the different specifications of travel time and scheduling attributes. We are interested in this because of a number of reasons:

1. The specification of schedule delays as shown in Figure 3.1 becomes more complicated when uncertainty in travel time and arrival time are introduced. In that case, the actual arrival time is between an earliest and latest arrival time. In the choice models we can use the earliest, latest or some expected arrival time attribute in the utility function. We want to explore the influence of different specifications. The same occurs for the travel time attribute.
2. The specification of schedule delays in Figure 3.1 is only based on the arrival time of travelers. We expect that the rescheduling of the departure time may be of importance as well.
3. We asked respondents about departure time and arrival time constraints. We expect that these constraints can be of importance in scheduling decisions of travelers. It is expected that a high penalty is associated with rescheduling outside the acceptable ranges.

In **Error! Reference source not found.** an extension of Figure 3.1 is presented (for the case of schedule delay early) which contains all the elements interest to us. There is minimum and a maximum arrival time a result of uncertainty. There are departure and arrival time scheduling components and acceptability bandwidths.

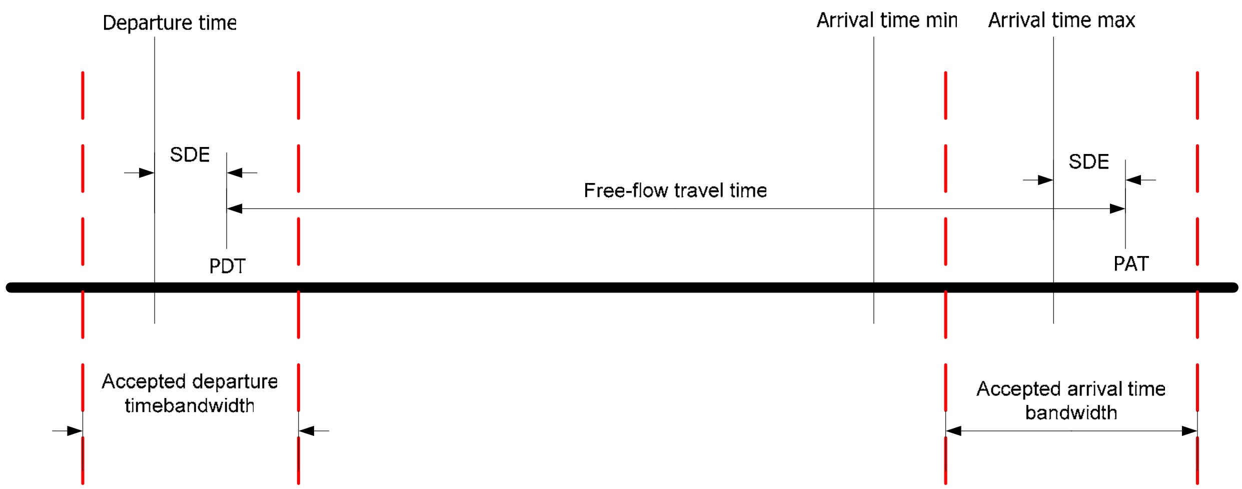


Figure 3.2: Extended focus on scheduling including departure side, uncertainty and acceptability bandwidths

For the purpose of comparison, the utility functions are as simple as possible and in this paper we only use linear in parameters MNL-models. As presented below, two utility functions are distinguished: one for car and one for public transport.

$$U_{car} = \beta_c C + \beta_\tau \tau_{car} + \beta_{ce} SDE_{car} + \beta_{cl} SDL_{car} + \beta_\omega \omega + \varepsilon$$
$$U_{pt} = PT + \beta_{\tau pt} \tau_{pt} + \beta_{pte} SDE_{pt} + \beta_{ptl} SDL_{pt} + \varepsilon$$

Where,

C = Road pricing charge in [euro]
τ_{car} = Travel time by car in [min]
SDE_{car} = Schedule delay early by car in [min]
SDL_{car} = Schedule delay late by car in [min]
ω = uncertainty in travel time by car in [min]
PT = alternative specific constant for public transportation
τ_{pt} = travel time by public transport in [min]
SDE_{pt} = Schedule delay early by public transportation in [min]
SDL_{pt} = Schedule delay late by public transportation in [min]

Since the public transport alternative does not include uncertainty this utility function remains unchanged in all the models presented in this paper and it consists of an alternative specific constant, travel time, schedule delay early and late (both based on preferred arrival time). The car utility functions for the different choice models differ in the specification of travel time and scheduling components. The specific utility functions used in the choice models will be discussed in detail in the next section of this paper. In this paper, we only present simple MNL models not taking into account any socio-economic variables of the respondents. In the assessing the statistical significance of estimates, we only roughly account for the correlation effect of repeated measurements of one respondent in the choice experiment by using a higher t-value when testing the significance of parameters.

4 Model results

4.1 Schedule delay vs. expected schedule delay

Due to the uncertainty in travel time the actual arrival time taken into account in the decision-making of respondents is unknown. The actual arrival time lies somewhere between the minimum and maximum arrival time which was presented to the respondents. In general there are an unlimited number of possibilities, but we take into account three options:

1. use the minimum arrival time ($AAT_{\min}$) as presented to respondents in the experiment;
2. use an expected arrival time ($eAAT$), calculated as the mean of the minimum and maximum arrival time;
3. use the maximum arrival time ($AAT_{\max}$) as presented to respondents in the experiment.

We estimated models for these three situations: the results are presented Table 4.1. For these estimations we used the specifications of scheduling delay components as presented below.

Departure time and arrival definitions:

$$PAT = \text{Preferred arrival time [min after 0:00 a.m.]}$$

$$PDT = \text{Preferred departure time [min after 0:00 a.m.]}$$

$$PDT = \text{PAT} - \tau_{\text{ff}}$$

$$\tau_{\text{ff}} = \text{Free-flow travel time}$$

$$ADT = \text{Actual departure time presented to respondent}$$

$$AAT_{\min} = ADT + \tau_{\min}$$

$$AAT_{\min} = \text{Earliest possible arrival time}$$

$$AAT_{\max} = ADT + \tau_{\max} = ADT + \tau_{\min} + \omega$$

$$AAT_{\max} = \text{Latest possible arrival time}$$

$$eAAT = \text{mean or expected arrival time}$$

$$eAAT = \frac{AAT_{\min} + AAT_{\max}}{2} = AAT_{\min} + \frac{\omega}{2}$$

Specifications of schedule delay parameters used in model 1 (SDMIN):

$$SDE_{arr\min} = \text{arrival schedule delay early based on earliest arrival time}$$

$$SDE_{arr\min} = \max\{PAT - AAT_{\min}, 0\}$$

$$SDL_{arr\min} = \text{arrival schedule delay late based on earliest arrival time}$$

$$SDL_{arr\min} = \max\{AAT_{\min} - PAT, 0\}$$

Specifications of schedule delay parameters used in model 2 (SDMAX):

$$SDE_{arr\max} = \text{arrival schedule delay early based on latest arrival time}$$

$$SDE_{arr\max} = \max\{PAT - AAT_{\max}, 0\}$$

$$SDL_{arr\max} = \text{arrival schedule delay late based on latest arrival time}$$

$$SDL_{arr\max} = \max\{AAT_{\max} - PAT, 0\}$$

Specifications of schedule delay parameters used in model 3 (ESD1TTMI):

$$eSDE_{arr} = \text{arrival schedule delay early based on mean arrival time}$$

$$eSDE_{arr} = \max\{PAT - eAAT, 0\}$$

$$eSDL_{arr} = \text{arrival schedule delay late based on mean arrival time}$$

$$eSDL_{arr} = \max\{eAAT - PAT, 0\}$$

Table 4.1: Model results for different specifications of schedule delays

	SDMIN		SDMAX		ESD1TTMI	
Variable	**Parameter**	**t-ratio**	**Parameter**	**t-ratio**	**Parameter**	**t-ratio**
		CAR				
Charge	-0.113	-18.50	-0.112	-18.37	-0.113	-18.49
Minimum travel time	-0.022	-19.10			-0.022	-18.87
Maximum travel time			-0.022	-18.93		
Schedule delay early minimum	-0.015	-15.85				
Schedule delay late minimum	-0.052	-11.80				
Schedule delay early maximum			-0.032	-18.20		
Schedule delay late maximum			-0.007	-6.02		
Expected schedule early					-0.023	-18.32
Expected schedule late					-0.019	-10.31
Uncertainty	-0.009	-7.46	0.010	5.39	-0.010	-7.98
		PUBLIC TRANSPORT				
Alternative specific constant	-0.663	-6.71	-0.628	-6.40	-0.648	-6.59
Travel time	-0.025	-18.92	-0.025	-19.11	-0.025	-19.02
Schedule delay early	-0.018	-5.08	-0.020	-5.57	-0.020	-5.50
Schedule delay late	-0.012	-3.39	-0.012	-3.62	-0.013	-3.63
Log L	**-15478.1**		**-15442.3**		**-15444.7**	

	SDMIN	SDMAX	ESD1TTMI
Value of Time (VOT)	€ 11.68	€ 11.79	€ 11.68
Value of Schedule Delay Early (VoSDE)	€ 7.96	€ 17.14	€ 12.21
Value of Schedule Delay Late (VoSDL)	€ 27.61	€ 3.75	€ 10.09
Value of Reliability (VOR)	€ 4.78	- € 5.36	€ 5.31

In terms of loglikelihood value the model based on the expected schedule delays seems best, the corresponding parameters however are not satisfactory. The parameter values for both schedule delay early and late are less negative (provide less disutility per minute) than a minute of travel time which is not realistic especially for the schedule delay late. The model based on the maximum arrival time shows similar problems, in this case the uncertainty parameter becomes positive. This is not very surprising because from a maximum arrival time point of view a larger uncertainty means a bigger chance of arriving earlier. The model based on the minimum arrival time shows the best results from a behavioral standpoint. The parameters are significant and their relative weights are in line with expectations (based on results from other studies in the Netherlands). The different results for the different specifications of scheduling delay are also caused by differences in scale between the different specifications. This makes it much harder to compare results between the models and they should somehow be normalized. This will be topic of further research.

4.2 Schedule delay specification conditional on the location of the preferred arrival time relative to the minimum and maximum arrival time

In the previous section we looked at schedule delays only from an arrival time perspective. In this section we also consider the 'location' of the preferred arrival time relative to the minimum and maximum arrival time. The preferred arrival time is the used to calculate the schedule delays, but since uncertainty is included this is not that straightforward. There are three cases to take into account:

1. If the minimum and maximum arrival times are both earlier than the preferred arrival time we are certain about a schedule delay early situation (based on minimum, maximum or expected schedule delays).

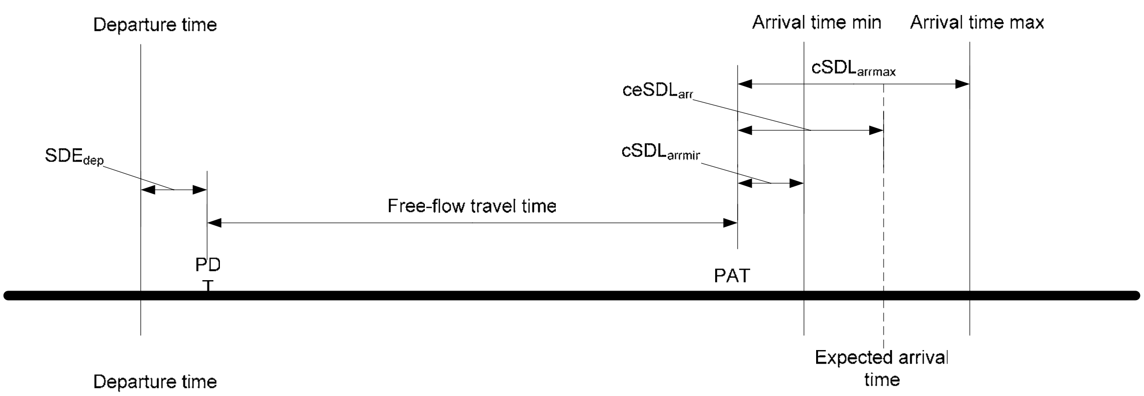
$$\delta_1 = \text{dummy} : 1 \text{ if preferred arrival time is later than latest arrival time, else } 0$$

$$cSDE_{arr\min} = SDE_{arr\min} \bullet \delta_1$$
$$cSDE_{arr\max} = SDE_{arr\max} \bullet \delta_1$$
$$ceSDE_{arr} = eSDE_{arr} \bullet \delta_1$$

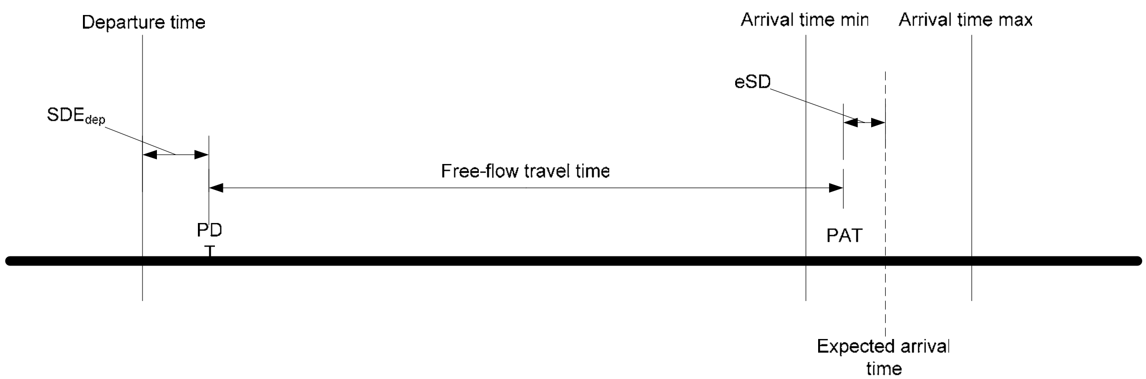
2. If the minimum and maximum arrival times are both later than the preferred arrival time we are certain about a schedule delay late situation (based on minimum, maximum or expected schedule delays).

$$\delta_2 = \text{dummy:1 if preferred arrival time is earlier than earliest arrival time, else 0}$$

$$cSDL_{arr\,\min} = SDL_{arr\,\min} \bullet \delta_2$$
$$cSDL_{arr\,\max} = SDL_{arr\,\max} \bullet \delta_2$$
$$ceSDL_{arr} = eSDL_{arr} \bullet \delta_2$$



3. The scheduling situation is undetermined when the preferred arrival time is between the minimum and maximum arrival time. In this case we use an expected schedule delay assuming a uniform distribution of arrival times between the minimum and maximum arrival time.



The three situations described above occur simultaneously in the data. In each choice alternative we identify which situation applies in this case using dummy variables. Using this approach we first estimated models using pure minimum (COND01), maximum (COND03) and expected (COND02) schedule delay specifications. Based on results from the previous steps we only used the minimum travel time in all models. We also specified two additional models in which minimum and maximum schedule delay specifications are mixed. In model 4 (COND04), we used a minimum specification for the schedule delay late and a maximum specification of the schedule delay early. In the figures above this is represented by *cSDEarrmax* and *cSDLarrmin*. In model 5 (COND05), we estimated a model using the opposite specification of model 4: maximum for late and minimum for early, resulting in *cSDEarrmin* and *cSDLarrmax* in the figures above. The model estimates are presented in Table 4.2.

Table 4.2: Model results for specification of schedule delays based on 'location' of preferred arrival time

	COND01		COND02		COND03		COND04		COND05	
Variable	**Parameter**	**t-ratio**	**Parameter**	**t-ratio**	**Parameter**	**t-ratio**	**Parameter**	**t-ratio**	**Parameter**	**t-ratio**
					CAR					
Charge	-0.112	-18.27	-0.112	-18.31	-0.112	-18.29	-0.111	-18.24	-0.112	-18.30
Travel time	-0.022	-19.00	-0.022	-19.12	-0.022	-19.21	-0.022	-18.99	-0.022	-19.27
Schedule delay early										
$cSDE_{arrmin}$	-0.015	-15.64							-0.015	-15.44
Schedule delay late										
$cSDL_{arrmin}$	-0.043	-9.03					-0.037	-8.11		
Schedule delay early										
$cSDE_{arrmax}$					-0.029	-16.62	-0.030	-16.92		
Schedule delay late										
$cSDL_{arrmax}$					-0.009	-7.18			-0.011	-8.48
Expected schedule			-0.021	-16.48						

delay early $cSDE_{arr}$										
Expected schedule delay late $cSDL_{arr}$			-0.017	-8.71						
Expected schedule delay early eSDE	-0.003	-0.73	-0.004	-0.85	0.004	0.82	0.004	0.85	-0.004	-0.92
Expected schedule delay late eSDL	-0.004	-1.21	-0.005	-1.54	0.001	0.37	0.002	0.69	-0.006	-1.70
Uncertainty	-0.013	-9.94	-0.013	-9.30	-0.015	-11.04	-0.015	-11.96	-0.012	-8.78
					PUBLIC TRANSPORT					
ASC	-0.662	-6.71	-0.647	-6.57	-0.643	-6.54	-0.679	-6.89	-0.624	-6.33
Travel time	-0.025	-18.91	-0.025	-19.04	-0.025	-19.09	-0.025	-18.85	-0.026	-19.19
Schedule delay early	-0.019	-5.34	-0.019	-5.40	-0.019	-5.40	-0.019	-5.37	-0.019	-5.38
Schedule delay late	-0.012	-3.56	-0.012	-3.56	-0.012	-3.53	-0.012	-3.51	-0.012	-3.57
Log L	**-15446.4**		**-15430.4**		**-15421.5**		**-15414.1**		**-15451.5**	

	COND01	COND02	COND03	COND04	COND05
VoT	€ 11.79	€ 11.79	€ 11.79	€ 11.89	€ 11.79
cVoSDEmin	€ 8.04				€ 8.04
cVoSDEmax			€ 15.54	€ 16.22	
cVoeSDE	N.S.	N.S.	N.S.	N.S.	N.S.
VoeSDE		€ 11.25			
cVoSDLmin	€ 23.04			€ 20.00	
cVoSDLmax			€ 4.82		€ 5.89
cVoeSDL	N.S.	N.S.	N.S.	N.S.	N.S.
VoeSDL		€ 9.11			
VoR	€ 6.96	€ 6.96	€ 8.03	€ 8.11	€ 6.43

The results show that in all the models the schedule delay parameters for cases where the preferred arrival time is between the minimum and maximum arrival time are not significant. Again the schedule delay parameters based on the maximum arrival time and expected arrival time have unexpected parameter values. What happens in these models (COND01, COND02 and COND03) is that the sensitivity of respondents towards rescheduling does not change, but that the parameter values only change because of changes in values (scale) of different scheduling specifications.

When comparing the models COND04 and COND05 the difference in scheduling parameter values can be explained by a difference in scale in the scheduling values themselves. However, since the scheduling delay values of COND05 include the travel time uncertainty, the uncertainty parameter is less negative and it drops somewhat in significance.

Based on the resulting loglikelihood values and the relative parameter values, model COND04 is the preferred model.

4.3 Distinguish schedule components on departure and arrival side

Based on the model COND04 from the previous section the scheduling delay components were extended to include scheduling components at the departure side of the trip. At the departure side of the trip uncertainty is not an issue when calculating the scheduling delays. We estimated four models in this section and the results are presented in **Error! Reference source not found.**.

The first (DEP01) is identical to the COND04 model from the previous section, but without the insignificant parameters. The second model (DEP02) includes both schedule delay early and late based on the preferred departure time. In model three (DEP03), the insignificant schedule delay early parameter for departure time is deleted from the model. In model four (DEP04), the schedule delay late for arrival time is also deleted since it was not that significant in DEP02.

$SDE_{dep} = \text{departure schedule delay early}$

$SDE_{dep} = \max\{PDT - ADT, 0\}$

$SDL_{dep} = \text{departure schedule delay late}$

$SDL_{dep} = \max\{ADT - PDT, 0\}$

Table 4.3: Model results including departure schedule delay components

	DEP01		DEP02		DEP03		DEP04	
Variable	**Parameter**	**t-ratio**	**Parameter**	**t-ratio**	**Parameter**	**t-ratio**	**Parameter**	**t-ratio**
				CAR				
Charge	-0.111	-18.29	-0.112	-17.42	-0.114	-18.63	-0.117	-19.23
Travel time	-0.022	-18.98	-0.024	-15.21	-0.023	-19.65	-0.024	-19.87
Schedule delay early								
$cSDE_{arrmax}$	-0.031	-18.51	-0.032	-12.42	-0.031	-18.65	-0.030	-17.92
Schedule delay late								
$cSDL_{arrmin}$	-0.039	-9.37	-0.029	-5.35	-0.031	-7.08		
Schedule delay early								
based on departure time SDE_{dep}			0.001	0.63				
Schedule delay late								
based on departure time SDL_{dep}			-0.078	-5.38	-0.078	-5.35	-0.112	-8.13
Uncertainty	-0.015	-12.80	-0.016	-11.89	-0.016	-13.32	-0.017	-14.74
				PUBLIC TRANSPORT				
Alternative specific constant	-0.682	-6.93	-0.679	-6.90	-0.681	-6.93	-0.642	-6.54
Travel time	-0.025	-18.84	-0.026	-18.90	-0.026	-19.34	-0.026	-19.76
Schedule delay early	-0.019	-5.38	-0.020	-5.62	-0.020	-5.61	-0.021	-5.82
Schedule delay late	-0.012	-3.52	-0.013	-3.73	-0.013	-3.73	-0.013	-3.90
Log L	**-15414.5**		**-15399.6**		**-15399.8**		**-15425.8**	

	COND01	COND02	COND03	COND04
VoT	€ 11.89	€ 12..86	€ 12.11	€ 12.31
cVoSDEmax	€ 16.76	€ 17.14	€ 16.32	€ 15.38
cVoSDLmin	€ 21.08	€ 15.54	€ 16.32	
$VoSDE_{dep}$		N.S.		
$VoSDL_{dep}$		€ 41.79	€ 41.05	€ 57.44
VoR	€ 8.11	€ 8.57	€ 8.42	€ 8.72

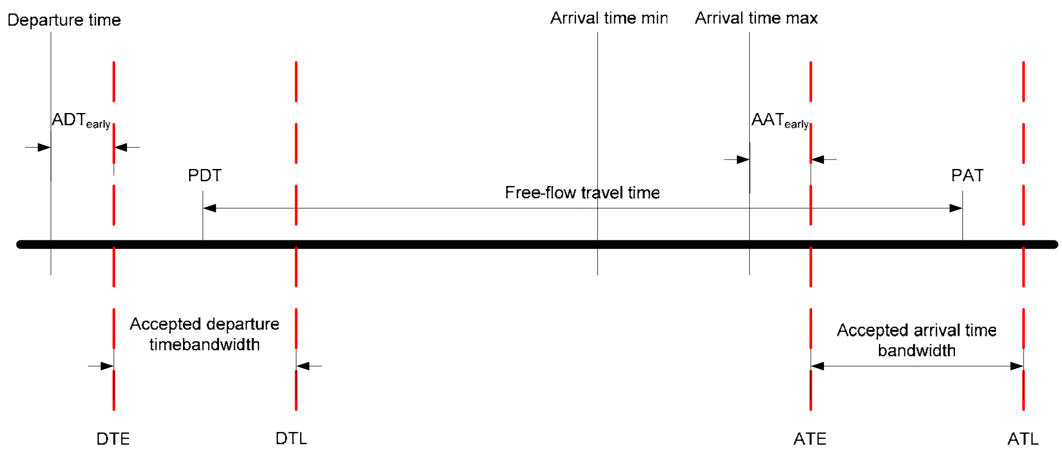
The results in **Error! Reference source not found.** show that especially the schedule delay late parameter based on departure time is significant and important. Next to the road pricing charge this parameter has the highest (negative) value in the car utility function. The introduction of the schedule delay late departure parameter does reduce the weight and level of significance of the schedule delay late arrival parameter. Both parameter are however simultaneously significant in the model. We cannot compare loglikelihood values in this case since the number of parameters in the model is not identical. The adjusted pseudo R-squared did increase between DEP01 and DEP03. Based on the results DEP03 is the preferred model.

From a behavioral point of view there remains the question how to explain the both the schedule delay late parameters are significant and why the late parameter based on preferred departure time has a much higher weight. In our survey we only included the home-to-work trip of which it is expected that on-time arrival is of importance. From our models it seems that on-time departure is much more important. A possible explanation is that respondents do think on-time arrival is important, but that if they depart on-time a late arrival at the workplace due to unforeseen delays (circumstances) is their fault. The importance of on-time arrival will be looked at in more detail in following sections.

4.4 Incorporate acceptable departure time and arrival time bandwidths

In the previous sections we only took into account scheduling delay components based on the preferred departure and arrival time of respondents. However, for each respondent we also know if there time restrictions at the departure and arrival side of the trip. In case there are restrictions we also know the lower and upper bound of acceptable departure and arrival times. We used these bandwidths to determine early and late departures and arrivals. At the arrival we compared the maximum arrival time with the lower bound acceptable arrival time. In case the maximum is earlier than the lower bound we are sure of an early arrival. Similarly we compare the minimum arrival time with the upper bound acceptable arrival time to determine a sure late arrival.

$$DTE = \text{earliest accepted departure time}$$
$$DTL = \text{latest accepted departure time}$$
$$ATE = \text{earliest accepted arrival time}$$
$$ATL = \text{latest accepted arrival time}$$
$$ADT_{early} = \text{Earlier departure than earliest acceptable departure time in minutes}$$
$$ADT_{early} = \max\{DTE - ADT, 0\}$$
$$ADT_{late} = \text{Later departure than latest acceptable departure time in minutes}$$
$$ADT_{late} = \max\{ADT - DTL, 0\}$$
$$AAT_{early} = \text{Earlier arrival than earliest acceptable arrival time in minutes}$$
$$AAT_{early} = \max\{ATE - AAT_{\max}, 0\}$$
$$AAT_{late} = \text{Later arrival than latest acceptable arrival time in minutes}$$
$$AAT_{late} = \max\{AAT_{\min} - ATL, 0\}$$



In the choice experiment the levels of time of travel start from deviations in the preferred arrival time. Using a specific level of travel time, the departure time is then later calculated. This provides a little more control about the used arrival time in the experiment than over the used departure time in the experiment. In

Table 4.4 we present the results of three of the models we estimated. In BAND01 is identical to the DEP03 model from the previous section. In BAND02 we added all the possible early and late variables. The results show that only the “departure time earlier than lower bound” is significant. We neglect the “departure time later than upper bound” parameter since the t-ratio’s are not yet corrected for using stated choice data. In the BAND05 model all the insignificant variables from the BAND02 model are deleted.

In the BAND05 model the parameters for schedule delay early and late based on arrival times are now identical and both significant. The imbalance between early and late scheduling components which are often found in other studies is fully captured by scheduling components at the departure side of the trip. There is a strong disutility associated with leaving later than the preferred departure time. In case of early departure there disutility associated with leaving earlier than the lower bound of the acceptable departure bandwidth.

Table 4.4: Model results taking into account acceptable departure and arrival bandwidths

	BAND01		BAND02		BAND05	
Variable	**Parameter**	**t-ratio**	**Parameter**	**t-ratio**	**Parameter**	**t-ratio**
	CAR					
Charge	-0.114	-18.63	-0.115	-18.82	-0.115	-18.82
Departure time earlier than lower bound [min] ADT_{early}			-0.016	-9.11	-0.016	-9.11
Departure ime later than upper bound [min] ADT_{late}			0.001	1.13		
Maximum arrival time earlier than lower bound [min] AAT_{early}			0.005	0.92		
Minimum arrival time later than upper bound [min] AAT_{late}			0.000	0.65		
Schedule delay late based on departure time: SDL_{dep}	-0.078	-5.35	-0.080	-5.48	-0.079	-5.48
Travel time	-0.023	-19.65	-0.023	-19.29	-0.023	-19.29
Schedule delay early: $cSDE_{arrmax}$	-0.031	-18.65	-0.030	-17.43	-0.029	-17.51
Schedule delay late: $cSDL_{armin}$	-0.031	-7.08	-0.032	-7.45	-0.032	-7.44
Uncertainty	-0.016	-13.32	-0.015	-13.03	-0.015	-13.07
	PUBLIC TRANSPORT					
Alternative specific constant	-0.681	-6.93	-0.686	-6.92	-0.702	-7.12
Travel time	-0.026	-19.34	-0.026	-19.13	-0.026	-19.13
Schedule delay early	-0.020	-5.61	-0.021	-5.67	-0.020	-5.66
Schedule delay late	-0.013	-3.73	-0.013	-3.86	-0.013	-3.84
Log L	**-15399.8**		**-15356.6**		**-15358.1**	

	BAND01	BAND02	BAND03
VoT	€ 10.91	€ 10.20	€ 10.20
cVoSDEmax	€ 12.12	€ 11.40	€ 11.40
cVoSDLmin	€ 10.91	€ 11.40	€ 11.40
$VoSDL_{dep}$	€ 40.00	€ 39.60	€ 39.60
$VoADT_{early}$		€ 5.40	€ 5.40
$VoADT_{late}$		N.S.	
$VoAAT_{early}$		N.S.	
$VoAAT_{late}$		N.S.	
VoR	€ 7.88	€ 7.80	€ 7.80

4.5 Importance of different utility components to total disutility

As an exercise we analyzed the relative disutility of different components in the utility function to the total disutility over all respondents in the dataset. From this analysis (Figure 4.1) we found the scheduling components are only responsible for about 9% of the total disutility. Travel time (with approximately 60%) is the largest source of disutility.

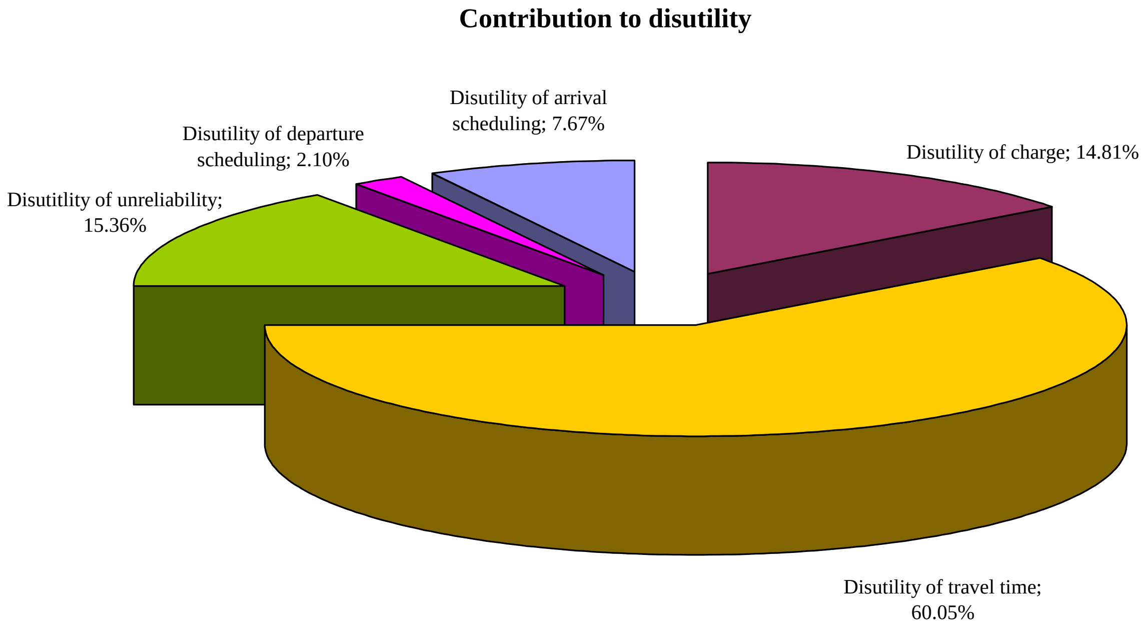


Figure 4.1: Contribution of different components to total disutility

5 Conclusions and further research

The standard approach of modeling departure or arrival time adjustments based only on the rescheduling around the preferred arrival time is not directly useable in the case uncertainty of travel time is included. Different specifications were tested and the models based on the minimum travel time and arrival time seem to produce the most plausible results. The differences in scale between alternative specifications of attributes however make it difficult to compare results. We are also interested to investigate this specification of scheduling components further using latent variable models.

The departure side of the trip is also found to be important in the scheduling of trips, but only a late departure was found to be significant. The value of late departure was found to be rather substantial, about €40,- per hour. Departing earlier than the earliest acceptable time does incur additional disutility. There are more scheduling components involved than just rescheduling based on the preferred arrival time. From a first analysis of the total disutility involved we do however find that the scheduling components do not represent a large portion of the total disutility. We still need to investigate the effect of scheduling components on the choice proportions of alternatives before we draw conclusions about the significance of scheduling components.

The values of travel time found in most of the models are reasonably consistent with other values of time found for commuters in the Netherlands (about €10,- per hour). The values of reliability or uncertainty of travel time we found are between €5,- and €8,- per hour. The uncertainty we included in this experiment is an uncertainty of travel time as a result of recurring congestion rather than uncertainty related to incidents or unpredictable events.

In some earlier modeling efforts we investigated the influence of some socio-economic variables and trip distance on model parameters and value of time components (Van Amelsfort and Bliemer, 2004). Using these new specifications of scheduling components we will investigate these influences in more detail. We will also use more complex choice models, for example non-linear effects of attributes and mixed logit models to investigate the heterogeneity in choice behavior.

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