# THE VALUE OF TRAVEL TIME VARIABILITY FOR DANISH CAR COMMUTERS

**Dereje F. Abegaz**
Department of Management Engineering
Technical University of Denmark
deab@dtu.dk

**Katrine Hjorth**
Department of Management Engineering
Technical University of Denmark
kahj@dtu.dk

**Short paper submitted to hEART 2019**
Work in progress

February 15, 2019

**ABSTRACT**

In this paper we estimate the value of travel time variability (TTV), based on stated preference data from a sample of Danish car drivers. We apply two different models, measuring TTV by either the standard deviation or the variance of the travel time distribution. We analyze how the value of TTV varies with observed characteristics such as income and education, and derive a weighted value of TTV, which is roughly representative for the population of Danish car commuters.

***K*eywords** Valuation · Travel Time Variability · Stated Preference

## 1 Introduction

In this paper we estimate the value of travel time variability (VTTV) based on stated preference data from a sample of Danish car drivers. Travel time variability (TTV) is a measure of the extent of travel time unpredictability that travellers face when they plan their journey. It may arise due to day-to-day fluctuations in traffic demand, or due to traffic incidents and weather conditions affecting road capacity. TTV is costly for the society, and it should be included in cost-benefit analyses of transport and infrastructure projects in order to evaluate potential gains of reducing TTV. This requires that we know the monetary value of TTV. Official values have been estimated for the Netherlands, the UK, Norway, Sweden and several other countries (see Kouwenhoven *et al.* , 2014; Batley *et al.* , 2017, and the references therein), but so far not for Denmark.

Our analysis is based on the theoretical framework in Fosgerau & Karlström (2010) and Fosgerau & Engelson (2011), who consider journey scheduling choices under uncertain travel times, in the case where departure time choice is continuous. The two papers are based on different assumptions commuters' trip scheduling preferences, and yield different conclusions in terms of the appropriate valuation of TTV. According to the former, the value of TTV is proportional to the standard deviation of travel time; in the latter, it is proportional to the variance of travel time. We therefore apply two different models to estimate the value of TTV, measuring the TTV by either the standard deviation or the variance of the travel time distribution.

We use data from a stated preference survey, where more than 1,000 Danish car commuters made hypothetical choices between journey alternatives with varying travel costs and distributions of travel time. We analyze how the value of mean travel time and the value of TTV vary with observed characteristics such as income and education, and derive weighted values of mean travel time and TTV, which are roughly representative for the population of Danish car commuters.

The survey was not designed to be representative of the Danish population. Instead, a stratified sampling approach was applied to sample two roughly equally sized sub-samples: one sub-sample consisting of travellers who usually

**Choice situation 1 out of 12**

**Which journey do you prefer?**

You choose your own departure time. Your preferred departure time may differ between A and B.

| | **Journey A** | **Journey B** |
|---|---|---|
| Travel time | 9 out of 10 times the journey takes **11** minutes | 8 out of 10 times the journey takes **10** minutes |
| | 1 out of 10 times the journey takes **20** minutes | 2 out of 10 times the journey takes **16** minutes |
| Cost | 20 DKK | 21 DKK |
| Your choice? | O | O |

Figure 1: Example of a choice screen (translated from Danish)

encounter congestion on the way to work, and another sub-sample consisting of travellers who are used to travel to work in uncongested conditions. The purpose of sampling equally from these two groups was to make sure we observed sufficient respondents who have experience with congestion on their daily commute. For research purposes, this sampling strategy is useful, because it provides a large sub-sample of people who are used to congestion and therefore possibly may have a different understanding of and experience with the situations presented in the choice experiments. However, it is obvious that this stratified sampling likely causes the overall sample to be biased compared to the population of car commuters. To obtain reliable valuations from the survey data, we weighted the sample to take into account that not all persons in the target population had equal probability of being selected into the sample.

## 2 Data

Most of this section derives from Abegaz *et al.* (2017).

### 2.1 The stated preference survey

The data originates from an Internet stated preference survey carried out in Denmark during the spring 2014. The survey was targeted at morning commute trips for car drivers, and was designed to estimate preferences for trip scheduling and TTV. The recruitment of respondents was handled by a market research agency, Epinion, using their existing Internet panel.

During the sampling period, 29th April - 22nd May 2014, 7456 respondents in Epinion's Internet panel were invited to participate in our survey. These were all people satisfying our sampling criteria: i) They used their car to commute to work during the 10 days preceding the date of the survey, ii) this commute lasted at least 10 minutes, and iii) they arrived at work between 7:00 a.m. and 9:00 a.m. An additional screening question,"Do you often experience problems with congestion and queues on your trip to work?", was used to separate respondents into our two sub-samples. In total, 1335 respondents participated in the survey, corresponding to a response rate of 18%.

The survey uses customized Internet questionnaires consisting of a series of questions related to the traveller's most recent, morning trip to work, *the reference trip*, e.g. departure time, travel time, restrictions on departure and arrival times, number of stops along the way, and (variable) trip cost. The survey contains two Stated Preference (SP) games, each consisting of 6 binary choices. One game involves trade-offs between mean travel time, TTV and the monetary cost of the trip, while the other also includes departure time. In the current paper, we only use data from the former SP game. Figure 1 shows an example of a choice screen from the game. An overall aim in the survey was to keep the SP trade-offs as simple as possible, and hence TTV is described using travel time distributions that can attain only two values, a high value with probability $p$ and a low value with probability $(1-p)$. The probability of an outcome is phrased as '*x out of 10 times, travel time is ... minutes*', to avoid direct mentioning of the concept of probabilities. We deliberately avoid the phrasing of travel times as 'normal travel time' and 'delay', to minimize effects of potential reference-dependence and loss aversion (Kahneman & Tversky, 1979).

The levels of the travel time and cost attributes are defined by pivoting around reference values, which are the experienced travel time and computed cost of the reference trip, and the number of gains and losses are balanced in the design.

For the sake of the statistical analysis, we have deliberately sought to ensure a wide range of attribute levels, rather than limiting analysis to 'realistic' ones. The ratio between the smallest and the largest of the four time attributes can be up to 2, such that the maximum travel time attribute can be as large as twice the size of the reference travel time, while the minimum travel time attribute can be as small as half the size of the reference travel time. The probability $p$ can take the values $0.1, 0.2, 0.4, 0.6, 0.8, 0.9$, to allow for as much variation as possible in the relation between mean travel time and variance. The cost attribute varies in both directions by up to 500 DKK multiplied by the sum of the absolute deviations of the means and standard deviations of the two alternatives.

The SP games were designed using an orthogonal and partly randomized design rather than an 'optimized design'. This is due to robustness considerations since the optimized design requires the true scheduling model to be known in advance, and the point of the survey was to investigate different possible models.

### 2.2 Sample statistics and description

We omit from our analysis 116 individuals who did not complete all 12 SP choices or had an interview duration of more than 24 hours. We also exclude 80 students and pensioners with part-time jobs, since we wish to focus on people whose primary occupation was as wage earners or self-employed. The remaining sample consists of 1139 respondents. For robustness reasons, the analysis does not include the following respondents:

- Nine respondents with three or more stops between home and work on their reference journey. We suspect that these people may interpret TTV differently than people with few or no stops, because a large part of the variation in travel time could be interpreted as due to the many stops along the way, and respondents with many stops may think they have the possibility to avoid some of the variability simply by rescheduling to move some of their errands to another (less congested) time of day.
- 80 individuals with reference travel time above 100 minutes or reference cost above 200 DKK: Due to the SP design, these respondents will experience rather large time and cost attribute values, and despite there are only a few respondents with such extreme values, they might have a substantial effect on the results, since the travel time variance can become very large and cause numerical problems in the likelihood optimization algorithm.

Eventually, estimation is based on 1050 respondents representing 78.65% of the total survey participants. The sub-sample used to congestion makes up 45.7% of the estimation sample. Most respondents commute on a daily basis and work full time. Most respondents have working times with partly or fully fixed hours, and less than a fifth have fully flexible working hours. About two-thirds of respondents have constraints regarding the time at which they can depart from home or arrive at work, out of which 17% have constraints at both the origin and destination and 88% have constraints at the destination. Compared to respondents with no constraints, a higher proportion of those with constraints are female (54% vs 37%), has children aged 10 years or below (31% vs. 16%), made at least one stop on their latest commute trip (22% vs. 12%), and has fixed working hours (45 vs 37%).

#### 2.2.1 The Danish National Travel Survey (TU)

We use data from the Danish National Travel Survey (TU) to calculate the weights we apply to compute representative values based on the survey sample. TU is a nationally representative survey documenting the travel behavior of the Danish population. It records detailed information about daily trip patterns for a large sample of people, together with information about their socio-demographic status, and the sample contains weights to compute statistics representative of the full population.

From TU, we use the sub-sample of morning car commute trips (outbound) with maximum two stops on the way from home to work, as this corresponds to our survey data. We use data from weekdays (Mon-Fri) in 2011-2014, where the TU interviewee was 18-87 years old.

## 3 Methodology

### 3.1 Model specification

We estimated the value of travel time and travel time variability using a mean-dispersion model:

$$u = -c + \theta_1 \mu + \theta_2 \rho(T) \quad (1)$$

where the optimal expected utility ($u$) obtained as commuters choose departure times optimally is defined in terms of monetary cost ($c$), the mean travel time ($\mu$) and a measure of the variability of travel time ($\rho(T)$), with $\theta_1$ and $\theta_2$ being parameters to be estimated. Two versions of this model are considered: the mean-standard deviation (MS) model where the standard deviation is used as the measure of TTV and the mean-variance (MV) model where $\rho(T)$ is the variance of the travel time distribution.

The MS and MV models are derived from underlying scheduling models assuming that travellers choose departure time optimally taking the distribution of travel times as given. Fosgerau & Karlström (2010) showed that the MS model can be obtained as a reduced-form of the step model of scheduling preferences (Vickrey, 1969; Small, 1982), which considers a commuter who has a preferred arrival time and derives utility at a constant rate at the origin while the utility rate at destination can take on a lower or higher value depending on whether the commuter arrives earlier or later than their preferred arrival time. Similarly, Fosgerau & Engelson (2011) showed that the MV model can be derived from the slope model of scheduling preferences (Vickrey, 1973; Tseng *et al.* , 2009) with a constant marginal utility of time at the origin and a linearly increasing utility rate at the destination.

Estimation is performed using a logit model with multiplicative errors with the choice utility of a given alternative specified as:

$$U = -\log\left(c + \exp\left(X_1\beta_1 + \theta_1\right)\mu + \exp\left(X_2\beta_2 + \theta_2\right)\rho(T)\right) + \frac{\epsilon}{\eta} \tag{2}$$

where $\epsilon$ is a random error that is Gumbel distributed with scale parameter 1 and is independent across observations and alternatives, $\eta$ is an error scale parameter to be estimated, and $X_1$ and $X_2$ are vectors of covariates with associated parameters $\beta_1$ and $\beta_2$. In this model, both the value of travel time, $VTT = \exp\left(X_1\beta_1 + \theta_1\right)$, and the value of travel time variability, $VTTV = \exp\left(X_2\beta_2 + \theta_2\right)$, depend on the parameter estimates and data.

### 3.2 Weighting

Weighting is performed as follows:

1. We classify the survey respondents into a set of segments.
2. For each segment $i$, we calculate a segment weight $W_i$, using data from TU.
3. Each survey respondent in segment $i$ is assigned the weight $w_i = \frac{W_i}{N_i}$, where $N_i$ is the number of survey respondents in segment $i$.
4. We compute values of mean travel time and TTV for each survey respondent and use the individual weights to compute weighted distributions of the values of travel time and variability.

We define a large set of segments in terms of various segmentation variables and criteria. Segmentation variables consist of respondent characteristics including their age, commute distance, the rate of urbanization in the workplace municipality, household type defined in terms of income and marital status and a dummy indicator for whether the household has at least one child under the age of 18 years. The criteria associated with each segmentation variable is outlined in Table 1. We require at least 10 TU interviewees in each segment, so we aggregate segments with less than 10 interviewees, by omitting the criteria about age and children for these segments.

Many respondents in both the TU and survey data have missing household income information.[1] We include survey respondents with missing income when we estimate our model, and use a dummy variable to capture the average valuation of this group. When computing weighted values of VTT and VTTV, we omit the respondents with missing income, as it is not obvious which weight they should be assigned to obtain representative values.[2] Segments with missing income information are therefore assigned a segment weight of zero.

## 4 Results and discussion

### 4.1 Parameter estimates

In an initial modelling stage, the model in (2) was estimated including a range of socioeconomic variables in $X_1$ and $X_2$. However, many of the socioeconomic variables were not statistically significant. Here, we present the results of a

[1] About 13% of survey respondents and 36% of the TU interviewees.

[2] Using the Mean-Variance model, we tested if there is structural difference in preferences between respondents with and without valid income information. We did this by estimating a restricted model based on a pooled sample and comparing it to separate models for a sub-sample of respondents with and without valid income information, which together represent the unrestricted model. The hypothesis that preferences are similar between the two groups is rejected at the 0.1% level for both models.

Table 1: Segmentation variables and criteria

| Segmentation variable | Criteria and coding |
|---|---|
| **Rate of urbanization**: Population density and rate of urbanization in workplace municipality as per Eurostat definition. | 1 Densely populated municipalities<br>2 Moderately populated municipalities<br>3 Sparsely populated municipalities |
| **Household type**: defined in terms of household income and marital status. The criteria are defined based on the weighted median of annual household income in the TU data, which is DKK 365,000 for single and DKK 757,000 for married households. | 1 Single respondent with below median income<br>2 Single respondent with above median income<br>3 Single respondent with missing income information<br>4 Respondent with spouse and below median income<br>5 Respondent with spouse and above median income<br>6 Respondent with spouse and missing income information |
| **Child/children** under 18 years in the household | 1 If true<br>0 Otherwise |
| **Respondent age** | 1 Respondent is at most 30 years old<br>2 Respondent age between 31 – 50 years, inclusive<br>3 Respondent is at least 51 years old |
| **Commuting distance** | 1 Below median commuting distance<br>2 Above median commuting distance |

simple model including the gross annual household income in both $X_1$ and $X_2$; and a dummy indicator for whether a respondent has completed two or more years of schooling at a higher education in $X_1$ only. We tested if the income parameters in $\beta_1$ and $\beta_2$ were significantly different: This was not the case, and hence the reported model assumes that elasticity of income is the same for VTT and VTTV (i.e. the corresponding values in $\beta_1$ and $\beta_2$ are identical).

The estimation results are summarized in Table 2.[3] Parameter estimates from the MS model are very similar to those from the MV model with the exception of the estimate of $\theta_2$. This is to be expected as the only difference between the two models is the measure of the TTV. In terms of model fit, the MV model has achieved a slightly higher log-likelihood value.

Table 2: Estimation results form the MS and MV models

| | MS model | MV model |
|---|---|---|
| Coefficient associated with the mean travel time ($\theta_1$) | -0.43 (0.29) | -0.42 (0.29) |
| Coefficient associated with a measure of TTV ($\theta_2$) | -1.03 (0.33)$^{**}$ | -1.39 (0.34)$^{**}$ |
| Scale parameter ($\eta$) | 3.92 (0.23)$^{**}$ | 3.77 (0.21)$^{**}$ |
| *Variables with identical effect on the VTT and the VTTV* | | |
| Logarithm of household income (in DKK 100,000) | 0.43 (0.14)$^{**}$ | 0.42 (0.14)$^{**}$ |
| Dummy indicator for high (> DKK 2 million) household income | 0.26 (0.63) | 0.28 (0.63) |
| Dummy indicator for low ($\leq$ DKK 100,000) household income | 0.97 (0.64) | 0.93 (0.68) |
| Dummy indicator for missing household income | 0.84 (0.32)$^{*}$ | 0.83 (0.32)$^{*}$ |
| *Variables with effect on the VTT alone* | | |
| Respondent has completed at least two years at higher education | 0.19 (0.13) | 0.19 (0.13) |
| Log-likelihood value at convergence | -4031.34 | -4029.36 |
| Number of estimated parameters | 8 | 8 |
| Number of respondents | 1050 | 1050 |
| Number of observations | 6300 | 6300 |

In parenthesis are robust standard errors clustered at the level of the individual respondent
$^{**}$ and $^{*}$ respectively indicate significance at the 5% and 10% levels

In addition to household income per se, the model includes a dummy indicator for high and low household income levels in order to account for the presence of outlier income information. However, neither of these dummy variables turned out to be significant. Similarly, a dummy for missing household income was also included and its estimate is marginally significant.

[3]Standard errors are clustered at the individual level to account for the panel structure of the data.

### 4.2 Weighted values of travel time and variability

Weighted values of travel time and TTV are computed using the survey data, parameter estimates reported in Table 2 and sampling weights following the steps outlined in Section 3.2. The weighted mean and quartile values of travel time and TTV are shown in Table 3, while the overall distribution of these values is portrayed in Fig. 2 and Fig. 3. Accordingly, estimates of the VTT from the MS model are very similar to those estimated under the MV model. This is clearly portrayed in Fig. 3 and suggests that, as far as the VTT is concerned, the choice between the MS and the MV models is immaterial. Secondly, there is hardly any difference between the mean and median values, suggesting that the distribution of the values of travel time and TTV are approximately symmetrical, a feature reflected in Fig. 3 and Fig. 2. Third, the MS model implies that the ratio of the VTTV to the VTT is about 0.5. The value of this ratio, known as the reliability ratio (RR), indicates that a two minute reduction in the standard deviation of travel time is worth the same as a one minute saving in average travel time.

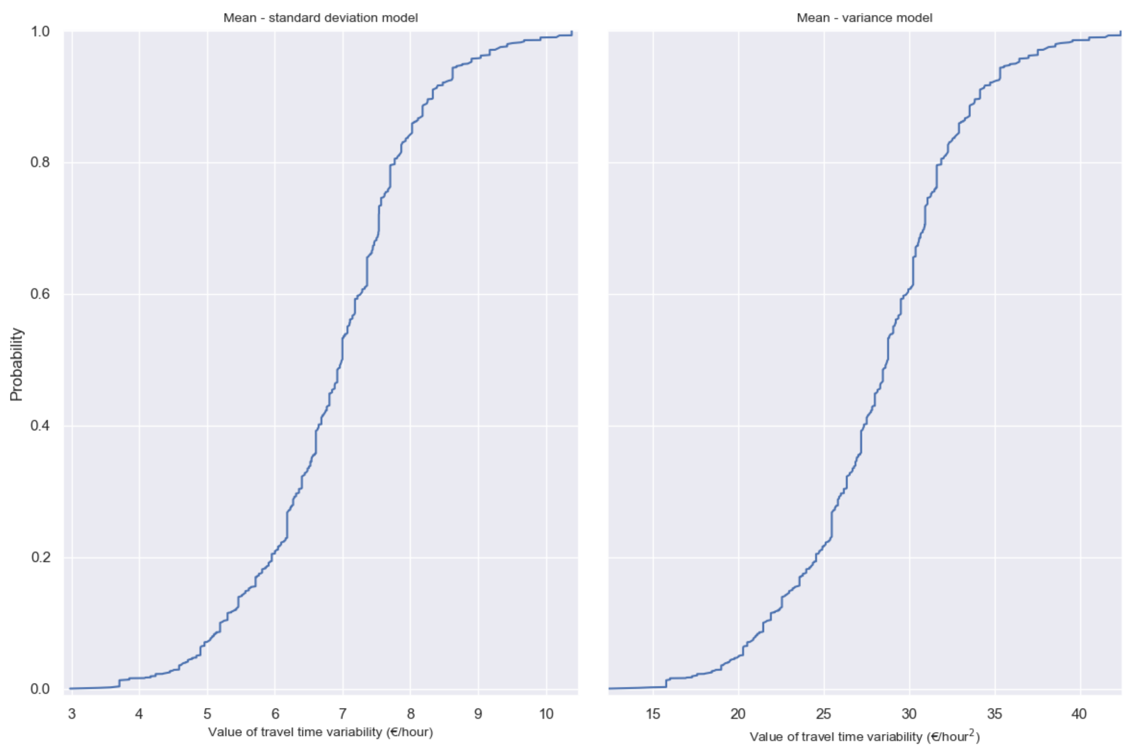


Figure 2: The VTTV from the MS model (left-hand side panel) and MV model (right-hand side panel)

Table 3: The mean and several quartiles of the values of travel time and TTV

| | Mean - standard deviation model | | Mean - variance model | |
|---|---|---|---|---|
| | VTTV (€/hour) | VTT (€/hour) | VTTV (€/hour$^2$) | VTT (€/hour) |
| First Quartile | 6.18 | 12.24 | 25.48 | 12.19 |
| Median | 7.00 | 14.40 | 28.78 | 14.35 |
| Mean | 6.90 | 14.43 | 28.36 | 14.36 |
| Third Quartile | 7.62 | 16.62 | 31.29 | 16.50 |

Comparing the value of TTV derived from the MV model against the same value from the MS model is not easy due to a difference in the unit of measurement. Since we are not aware of any official value of TTV estimated based on the MV model, we have no reference to compare to. The ensuing discussion on how our estimate of the VTTV fares against those in the literature is based on our results from the MS model.

Our estimated values of travel time and TTV as well as the reliability ratio are comparable with corresponding values for other countries. A recent Dutch study by Kouwenhoven *et al.* (2014) recommended to use 3.75 €/hour as the

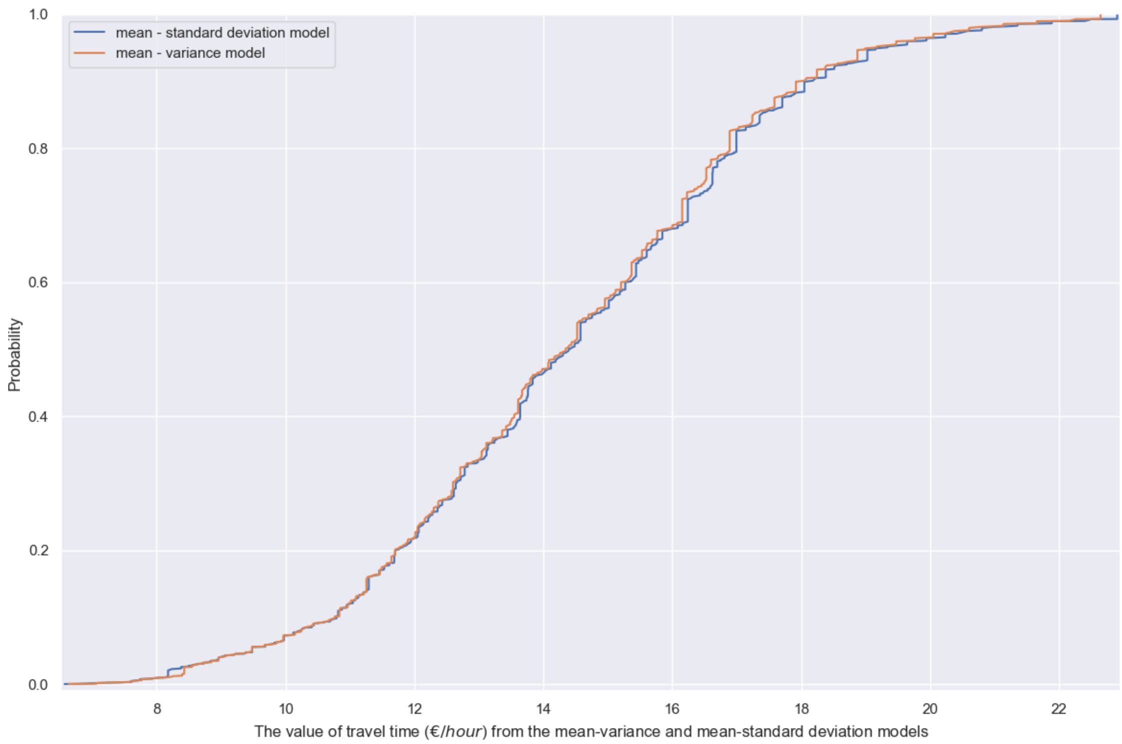


Figure 3: The value of travel time

VTTV in economic appraisal of transport projects in The Netherlands. This value is about 54% lower than the weighted average value of the VTTV in the current paper. A review of the international literature shows that estimated reliability ratio values can range between 0.3 to 1.1 (Kouwenhoven *et al.* , 2014), although an earlier review by Carrion & Levinson (2012) shows a much wider range. The reliability ratio in the current paper lies within this range and is comparable to values in the Dutch study (RR=0.4) and the Norwegian study from 2010 (RR=0.42, cf. TØI, 2010) for car commuters. Similarly, the weighted mean VTT in this paper (14.4€ /hour) is comparable to the values in the Dutch study (9.25€ /hour), Swedish study (9.2 - 12.1€ /hour) and Norwegian study (12.13 - 26.95€ /hour) for commute trips by car (Kouwenhoven *et al.* , 2014).

## 5 Conclusion

We used data from a stated preference survey to establish new values of travel time variability for Danish car commuters. Since the data used in estimation did not come from a nationally representative survey, we used sample weights calculated based on data from the Danish National Travel Survey and applied the weights to compute representative values of travel time variability. In the absence of an officially recommended value for the marginal cost of travel time variability, the estimated average values of travel time variability, i.e., € 6.9 per hour and € 28.4 per hour-squared, can be used in economic appraisal of transport projects in Denmark.

## References


Abegaz, D., Hjorth, K., & Rich, J. 2017. Testing the slope model of scheduling preferences on stated preference data. *Transportation Research Part B: Methodological*, **104**, 409–436.

Batley, Richard, Bates, John, Bliemer, Michiel, Börjesson, Maria, Bourdon, Jeremy, Cabral, Manuel Ojeda, Chintakayala, Phani Kumar, Choudhury, Charisma, Daly, Andrew, Dekker, Thijs, Drivyla, Efie, Fowkes, Tony, Hess, Stephane, Heywood, Chris, Johnson, Daniel, Laird, James, Mackie, Peter, Parkin, John, Sanders, Stefan, Sheldon, Rob, Wardman, Mark, & Worsley, Tom. 2017. New appraisal values of travel time saving and reliability in Great Britain. *Transportation*, 1–39.

Carrion, Carlos, & Levinson, David. 2012. Value of travel time reliability: A review of current evidence. *Transportation Research Part A: Policy and Practice*, **46**(4), 720–741.

Fosgerau, Mogens, & Engelson, Leonid. 2011. The value of travel time variance. *Transportation Research Part B: Methodological*, **45**(1), 1–8.

Fosgerau, Mogens, & Karlström, Anders. 2010. The value of reliability. *Transportation Research Part B: Methodological*, **44**(1), 38–49.

Kahneman, Daniel, & Tversky, Amos. 1979. Prospect Theory: An Analysis of Decision under Risk. *Econometrica*, **47**(2), 263–291.

Kouwenhoven, Marco, de Jong, Gerard C., Koster, Paul, van den Berg, Vincent A. C., Verhoef, Erik T., Bates, John, & Warffemius, Pim M. J. 2014. New values of time and reliability in passenger transport in The Netherlands. *Research in Transportation Economics*, **47**(Nov.), 37–49.

Small, Kenneth A. 1982. The Scheduling of Consumer Activities: Work Trips. *The American Economic Review*, **72**(3), 467–479.

Tseng, Yin-Yen, Verhoef, Erik, de Jong, Gerard, Kouwenhoven, Marco, & van der Hoorn, Toon. 2009. A pilot study into the perception of unreliability of travel times using in-depth interviews. *Journal of Choice Modelling*, **2**(1), 8–28.

TØI. 2010. *Den norske verdsettingsstudien, Sammendragsrapport*. Report for the Norwegian Ministry of Transport, Institute of Transport Economics, Oslo, Report no. 1053/2010.

Vickrey, William. 1969. Congestion Theory and Transport Investment. *The American Economic Review*, **59**(2), 251–260.

Vickrey, William. 1973. Pricing, metering, and efficiently using urban transportation facilities. *Highway Research Record*, **476**, 36–48.