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Prediction of travel time variability for cost-benefit analysis

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ABSTRACT

Unreliable travel times cause substantial costs to travelers. Nevertheless, they are often not taken into account in cost-benefit analyses (CBA), or only in very rough ways. This paper aims at providing simple rules to predict variability, based on travel time data from Dutch highways. Two different concepts of travel time variability are used, which differ in their assumptions on information availability to drivers. The first measure is based on the assumption that, for a given road link and given time of day, the expected travel time is constant across all working days (rough information: RI). In the second case, expected travel times are assumed to reflect day-specific factors such as weather conditions or weekdays (fine information: FI). For both definitions of variability, we find that the mean travel time is a good predictor. On average, longer delays are associated with higher variability. However, the derivative of variability with respect to delays is decreasing in delays. It can be shown that this result relates to differences in the relative shares of observed traffic 'regimes' (free-flow, congested, hyper-congested) in the mean delay. For most CBAs, no information on the relative shares of the traffic regimes is available. A non-linear model based on mean travel times can then be used as an approximation.

1. Introduction

Travel times on roads are usually not stable over time. Variations occur in demand for travel as well as in road capacity, and these cause travel times to vary. Parts of these fluctuations are known to travelers. Especially frequent travelers are aware of recurrent congestion patterns during peak hours, or the adverse effect of heavy rain on travel times. This paper focuses on variations in travel times that are not expected by drivers. They cause drivers to arrive at their destinations earlier or later than expected. In most cases, such schedule delays come at a cost to drivers. They might face waiting times, or the need to reschedule activities. With most people being risk-averse, the uncertainty of arrival time might be accompanied by feelings of stress and anxiety.

To include the costs associated with unreliable travel times in cost-benefit analysis (CBA), both the drivers' (monetary) valuation of unreliable travel times and the extent of unreliability need to be known. While the values that drivers attach to travel time variability and schedule delays have been derived in various stated and revealed preference experiments (e.g. Hensher, 2001; Lam and Small, 2001; Small, 1982), only little research has been done on explaining and forecasting the extent of travel time variability. Most of the research in this area is based on simulation studies. The outcomes of these studies are usually not easily transferable to CBA, as they focus on stylized cases of traffic networks without the use of empirical data (e.g. Nicholson and Du, 1997; Li et al., 2009; Nagel and Rasmussen, 1995). Studies that explicitly predict the variability of travel times based on empirical data, and calculate the resulting costs, were done by Eliasson (2006), Fosgerau

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et al. (2008). They both point out the importance of including variability-related costs into CBA, suggesting that 10–15% of the costs associated with changes in travel times can be attributed to changes in variability.

A common result of previous research is that the main explanatory factor of travel time variability is mean travel time. Fosgerau (2010) proves that, under the assumptions of Vickrey's bottleneck model, if mean travel times are increasing between two time periods, the standard deviation of travel times increases as well. However, he also shows that the mean and the standard deviation vary differently from each other during the peak. Kouwenhoven et al. (2005) show empirically that a higher mean travel time usually implies a higher level of variability. Eliasson (2006) derives similar results but he also shows that if congestion is very severe, variability can become a decreasing function of travel time.

Also in the current paper, we find a non-linear relationship between travel time variability and mean travel time. We investigate whether the non-linearity can be attributed to different 'traffic regimes'. The regimes can be defined according to their location in the speed-flow relationship of traffic, which follows from the so-called fundamental diagram of traffic that shows how speeds fall with traffic density (Greenshields, 1935; Kerner, 2004; Hall et al., 1992; Hall, 2002; Haight, 1963). In this paper we distinguish between the free-flow, congested and hyper-congested regime. The free-flow regime refers to travel speeds close to free-flow speed, and flow rates considerably lower than the maximum capacity of a road segment. The congested regime describes conditions where travel times are significantly higher than free-flow travel times, and flow is relatively close to maximum capacity. Finally, hyper-congestion occurs if the traffic density that implies a maximum flow (capacity) is exceeded and queuing takes place, leading to a below-maximum flow and considerable delays. In terms of the speed-flow curve plotting traffic flow on the horizontal and speed on the vertical axis, the free-flow and congested regimes are located at the upper (downward bending) segment of the curve, whereas the hyper-congested regime corresponds with the lower (upward bending) section of the curve.

Only few papers have looked explicitly at the influence of flow on travel time variability. Tu et al. (2007) investigate the correlation between (in)flow variability and travel time variability. They find that travel time variability is hardly related to the variability of flow in the free-flow and hyper-congested regime, whereas it is positively correlated with flow variability in the congested regime.[1] In the current paper, in contrast, we focus on the impact of the relative shares of the traffic regimes on variability.

The current paper also introduces two measures of travel time variability. These differ in the assumption on the extent of information available to drivers. The first measure is based on the assumption that for a given road link, and a given time of the day, expected travel times are constant over the entire year. We will call this "rough information" (RI). The second measure assumes that drivers adjust expectations on travel times according to (public) information on weather conditions, weekday, season and demand patterns, and will be referred to as "fine information" (FI).

This paper thus contributes to the existing literature on predicting travel time variability by explaining the linkage of travel time variability and mean delay for different traffic regimes. The results give a clear indication that the relative shares of the traffic regimes have an impact on the relation between mean delays and standard deviation. Unlike earlier literature, this paper provides two measures of variability, and has a strong focus on the applicability of the results in CBA.

The paper is organized as follows. Section 2 provides an overview of the travel time data and the variables used in the analysis. Section 3 contains the empirical analyses. A non-traffic-regime based model (NTR) as well as a traffic-regime based model (TR) are derived, and results are analyzed. Section 4 proceeds by discussing the implications of the results for cost-benefit analysis. Finally, Section 5 provides concluding remarks and suggestions for further research.

2. Data and variables

The goal of the paper is to identify factors that determine travel time variability and to estimate their influence on variability. The focus is on variables that lend themselves for inclusion in CBA. That is, variables should be likely to be readily available to cost-benefit analysts (for instance as output of traffic models). Besides this, variables should not be defined at a too detailed level. CBA are usually used as an instrument to assess the costs and benefits of relatively large-scaled projects. Therefore, cost calculations based on very detailed variables are usually neither useful nor feasible.

2.1. Travel time data

For the econometric analysis we use travel time distributions of 145 (one-directional) highway links in the Netherlands. Since travel time data are not available for door-to-door trips, we focus on the highway network, which is very dense in the Netherlands. For this reason, almost 50% of all driving takes place on highways.[2] Fig. 1 shows a map of the Netherlands, indicating all road stretches included in the analysis. Most of them are concentrated in the West of the country, which is one of the most densely populated areas in Europe.

[1] Tu et al. (2007) define three traffic regimes: fluent traffic, transition traffic and capacity traffic. The definitions correspond closely to the ones used in this paper (free-flow, congested and hyper-congested traffic).

[2] This number refers to non-freight transport. The percentage is based on the number of km driven on Dutch highways in 2006 (around 50 billion km, assuming a 20% rate of freight transport) divided by the number of overall km driven (around 95 billion km).(Dutch Ministry of Transpor, 2008; Dutch Ministry of Transport, 2006)