Transportation Research Part C 24 (2012) 83–101

Contents lists available at SciVerse ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Valuing travel time variability: Characteristics of the travel time distribution on an urban road

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ARTICLE INFO

Article history:
Received 10 August 2010
Received in revised form 18 February 2012
Accepted 20 February 2012

Keywords:
Value of travel time variability
Travel time distribution
Nonparametrics
Stable distributions

ABSTRACT

This paper provides a detailed empirical investigation of the distribution of travel times on an urban road for valuation of travel time variability. Our investigation is premised on the use of a theoretical model with a number of desirable properties. The definition of the value of travel time variability depends on certain properties of the distribution of random travel times that require empirical verification. Applying a range of nonparametric statistical techniques to data giving minute-by-minute travel times for a congested urban road over a period of five months, we show that the standardized travel time is roughly independent of the time of day as required by the theory. Except for the extreme right tail, a stable distribution seems to fit the data well. The travel time distributions on consecutive links seem to share a common stability parameter such that the travel time distribution for a sequence of links is also a stable distribution. The parameters of the travel time distribution for a sequence of links can then be derived analytically from the link level distributions.

1. Introduction

Travel time variability (TTV) is increasingly recognized as an important issue in the economic appraisal of transport infrastructure investment as well as transport policies such as road pricing. The importance of reducing TTV on urban and interurban roads is considered a major objective of transport policy. The traveler's marginal value of TTV, often called the value of travel time variability (VTTV), should therefore play a significant role in project evaluation. This paper contributes to this aim by investigating the empirical validity of assumptions underlying a recent theoretical derivation of the VTTV based on scheduling costs.

There are two broad modeling approaches to the travelers' valuation of TTV. The first is commonly referred to as the mean–variance approach. This approach incorporates the effects of TTV into utility or cost functions of travelers simply by taking the standard deviation or some other measure of the scale of travel time variability as an argument, jointly with mean travel time. Because of its simplicity, the mean–variance approach has been widely used (Small et al., 2005; Brownstone and Small, 2005; Lam and Small, 2001, among others). The mean–variance approach has however been criticized on various grounds. A main criticism is that it does not take that shape of the travel time distribution into account. Another important criticism is that the standard deviation of travel time is not an outcome of a trip. Economic theory generally defines utility directly over outcomes.

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0968-090X/$ - see front matter
doi:10.1016/j.trc.2012.02.008

The main alternative is the scheduling approach, originally proposed by Small (1982) and extended to random travel times by Noland and Small (1995), Noland (1997), Noland et al. (1998). The scheduling approach defines travel cost directly over outcomes, which is an advantage relative to the mean–variance approach. The scheduling approach assumes that the travelers' cost function depends in a certain way on travel time and on the arrival time relative to a preferred arrival time. Given knowledge of departure time, the distribution of travel times and the preferred arrival time, it is possible to evaluate a measure of expected travel cost that includes scheduling considerations. However, direct application of the scheduling cost function requires knowledge of the departure time and the preferred arrival time, which may be unavailable.

The assumption that travelers choose departure time optimally may replace the information on departure time and preferred arrival time. The resulting measure of expected travel cost was derived for a few special travel time distributions by Bates et al. (2001), Noland and Polak (2002) when the travel time distribution does not depend on the departure time. It turns out that the scheduling model becomes equivalent to the mean–variance approach in these cases. These results depend, however, on specific and unrealistic assumptions concerning the distribution of random travel time.

Recently, Fosgerau and Karlström (2010) generalized these earlier results to the case where the distribution of travel times is arbitrary. Fosgerau and Karlström (2010) proved that the minimized expected cost of commuters is linear in the mean travel time and a scale measure of the travel time distribution, irrespective of the shape of the travel time distribution, provided that the travel time distribution does not depend on the departure time. Under the assumptions of their model (henceforth the FK model), the VTTV is given in terms of travelers' marginal cost of schedule delay and the average time late under the optimal departure time. The average time late is determined by the travelers' preferences and the distribution of travel times. The FK measure of VTTV may remain a good approximation when the mean and the scale of the travel time distribution depends on the time of day. Starting with observations of travel time, subtracting the mean and dividing by the scale of the travel time distribution at each time of day leaves the standardized travel time distribution. FK extended their result as an approximation when the standardized travel time distribution does not depend on the departure time.

This background motivates the present paper, which aims to carry out a check of the empirical validity of the FK assumptions regarding the distribution of travel times. It should be noted that Fosgerau and Engelson (2011) have developed an alternative approach to modeling the VTTV. This approach is based on another specification of scheduling preferences, derived from Vickrey (1973). The Fosgerau–Engelson measure of VTTV is not sensitive to the shape of the travel time distribution, but like FK it does require that the travel time distribution is independent of the time of day. Furthermore, the choice between the FK model and the Fosgerau–Engelson model should be based on which formulation of scheduling preferences is thought to be the best description of the scheduling preferences of travelers. Hence the investigation of this paper remains relevant in the light of the Fosgerau–Engelson result.

The first empirical question investigated in this paper is the validity of the FK assumption that the standardized travel time can be considered to be independent of the travelers' departure time. Independence of the standardized travel time of the time of day is also a great simplification since it becomes unnecessary to account for different travel time distributions at different times of day. In this case, all the variation in the travel time distribution over the day is captured by the mean and the scale of the travel time distribution. If independence does not hold then neither FK nor the Fosgerau–Engelson result is applicable.

The next empirical question regards the distribution of standardized travel times. It is useful to be able to assume that the travel time distribution belongs to a known parametric family. Fosgerau and Karlström (2010) found in their empirical work on a single road link that the empirical distribution of the standardized travel times is asymmetric and fat right-tailed, and far from normal. Furthermore, knowledge of the travel time distribution may facilitate the aggregation of the VTTV from the link level to a sequence of links. A detailed investigation of the distributional properties of standardized travel times has not been carried out. Such an investigation is a further contribution of this paper.

We investigate these empirical questions using a large data set comprising observations of travel times on an urban road. We use minute-by-minute observations of average travel times on four consecutive links of a major radial road in Copenhagen, collected over a period of five months.

The distribution of travel times on the urban road is analyzed using a range of nonparametric techniques, including mean regression, quantile regression and kernel based estimation of conditional distributions. Nonparametric mean regression and quantile regression are employed for computing standardized travel times. The conditional distribution of standardized travel time is estimated to check whether it is independent of time of day.

We anticipate that stable distributions (see Zolotarev (1986), Nolan (in press) for example) describe the distribution of travel times well. The family of stable distributions includes the normal as a special case. In general, this family allows distributions with skewness and heavy tails, as observed in empirical travel time distributions. Stable distributions have two important features. First, they arise as limits in the generalized central limit theorem. Second, the sum of independent stable random variables with a common stability parameter is again stable with the same stability parameter. As explained below, these two features are very attractive in relation to the FK model. In the paper we fit a stable distribution to standardized travel times and estimate the parameters that characterize the stable distribution. The goodness-of-fit for the estimated stable distribution is assessed in various ways and we examine whether the estimated stable distributions for different road links share a common stability parameter.

The paper proceeds as follows. Section 2 provides a brief description of the FK model. Section 3 explains the methodology used to investigate the statistical properties of travel time distributions. Section 4 presents our data. The empirical analysis is presented in Section 5. Finally, Section 6 concludes.