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Estimation and valuation of travel time reliability for transportation planning applications

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ABSTRACT

This paper proposes a method to measure the value, forecast, and incorporate reliability in the transportation planning process. Empirically observed travel time data from INRIX are used in an introduced method to measure Origin Destination (OD)-based reliability. OD-based reliability is a valuable concept, since it can be easily incorporated in most travel models. The measured reliability is utilized to find the value of reliability for a specific mode choice problem and to establish the relationship between travel time and reliability. This relationship is useful to forecast reliability in future scenarios. Findings are combined with Maryland Statewide Transportation Model to find the value of reliability savings by improving the network in a case study. The Inter-County Connector is used as the case study to show the significance of reliability savings. The proposed approach can be used to (1) provide a systematic approach to estimate travel time reliability for planning agencies, (2) incorporate travel time reliability in transportation planning models, and (3) evaluate reliability improvements gained from transportation network investments.

1. Introduction

An appropriate travel demand model is expected to predict travelers' choices with adequate accuracy. These choices primarily consist of departure time choice, mode choice, path choice and en-path diversion choice. Unpredictable variation in travel times of a specific mode, path, or time is one of the most important attributes considered by travelers. Travel time reliability (TTR) is defined as "the consistency or dependability in travel times, as measured from day-to-day and/or across different times of the day" (FHWA, 2009). The concept of TTR has been raised and employed in different studies to define and measure this unpredictable variation of travel time. According to Bhat and Sardesai (Bhat and Sardesai, 2006), travelers consider reliability for two main reasons. First, commuters may be faced with timing requirements, and there are consequences associated with early or late arrival. Second, they inherently feel uncomfortable with unreliability because it brings worry and pressure. This behavioral consideration has been noted in many studies where it is observed that some travelers accept longer travel times in order to make their trip more reliable (Jackson and Jucker, 1982).

Reliability has become a significant part of travel models since early studies (Gaver Jr, 1968; Prashker, 1979). Many theoretical and experimental studies have considered reliability in their departure time choice, path choice or mode choice models, using stated preference (SP) or revealed preference (RP) surveys. While SP surveys describe a hypothetical situation for respondents, RP surveys ask about their actual choice and do not contain usual perception errors found in SP surveys. While there are a number of reliability studies using SP surveys, there are few studies that utilize RP surveys due to the lack of experimental settings that have significant differences among alternatives, and hardships in planning and deploying these surveys and gathering the data (Carrion and Levinson, 2012). Bates et al. (Bates et al., 2001) claimed it was virtually impossible to find RP situations with sufficient perceived variation in reliability and other appropriately compensating components of journey utility. Although there are some good examples of departure time choice and path choice research using RP surveys (Carrion and Levinson, 2010, 2012; Lam and Small, 2001; Small, 1992), they all analyze TTR in link-level or path-level. There is no previous study about Origin-Destination (OD)-level TTR, even though OD level studies are extensively used in the literature (Alam, 2009; Alam et al., 2010; Raphael, 1998; Thompson, 1998). Since trip-based and activity-based travel demand analysis and modeling are usually conducted at

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the zone level, OD-level TTR measure would be of great value in incorporating reliability into current planning process.

The main contribution of this study is introducing an OD-based reliability approach on empirically observed data to be used in planning process. OD-based reliability is important because it can easily be incorporated in planning processes or travel models. Additionally, reliability and its value are measured and estimated using empirically observed travel times and household travel surveys, which can be easily available. This is very valuable since conducting new SP surveys for reliability is costly, and estimates based on SP surveys contain perception errors. The objective of this paper is to develop a framework to (1) measure travel time reliability, (2) determine the value of reliability, (3) incorporate reliability in transportation planning models, and (4) estimate changes in reliability because of new or proposed transportation infrastructure investments. This paper discusses various steps on how to consider reliability as a performance measure in planning and the decision-making process by making the best utilization of available data sources and planning models. Its application is also demonstrated in a real-world case study.

The remainder of the paper is organized as follows. In the next section, literature review of reliability estimation is presented, followed by a suggested methodology that can be easily adapted by planning agencies. The case study section describes application of the proposed methodology in a real world planning model. The result section discusses the importance of considering VoTR in the planning process. The conclusion section summarizes the proposed research and discusses future directions.

2. Literature review

To date a number of studies and research papers have been published, where the value of reliability was measured using SP survey, RP survey, corridor travel times, and an assessment of the impact of reliability in demand (trip based or activity based) and capacity (network cost based) models. In the review presented herein, literature is classified in four groups (1) reliability in travel demand models, (2) data sources used for modeling reliability, (3) valuation of travel time reliability, and (4) reliability application and performance measures.

2.1. Reliability in travel demand models

Reliability was introduced to travel models in early studies. Gaver Jr (Gaver Jr, 1968) proposed a departure time choice model and mentioned that travelers predict variance of their travel time and depart with a safety margin, which he called “Head start time”. Polak (Polak, 1987) stated that reliability should be an explicit term in the models, and added a reliability variable to a mode choice model, which showed statistically significant improvement. The path choice model developed by Jackson and Juker (Jackson and Jucker, 1982) can be considered as the first study that utilized expected utility theory and the concept of reliability together. Jackson and Juker (Jackson and Jucker, 1982) stated that travel time unreliability is a source of disutility in addition to travel time, and used a SP survey to assess the respondents’ tradeoffs between travel time and reliability, and also calculated user’s degree of risk aversion. The same method is used in other studies but with a different form of utility function (Polak, 1987; Senna, 1994). Reliability has also gone through network traffic equilibrium models where Mirchandani and Soroush (Mirchandani and Soroush, 1987) incorporated travel time variance in the utility function, and showed how users shifted their path to more reliable ones.

It is clear that reliability is an important measure of the health of the transportation system in a region, as state Departments of Transportation (DOTs) and Metropolitan Planning Organizations (MPOs) prepare to manage, operate and plan for future improvements. Travel time reliability, depicted in the form of descriptive statistics derived from the distribution of travel times is a critical indication of the operating conditions of any road. Considering its importance, transportation planners are inclined to include reliability as a performance measure to alleviate congestion. To investigate the use of travel time reliability in transportation planning, Lyman and Bertini (Lyman and Bertini, 2008) analyzed twenty Regional Transportation Plans (RTPs) of metropolitan planning organizations (MPOs) in the U.S. None of the RTPs used reliability in a comprehensive way, though a few mentioned goals of improving regional travel time reliability. Even though many studies have tried to measure behavioral response to reliability, their application in a transportation-planning context is limited. Studies were conducted to understand the reliability of specific paths (Chen et al., 2003; Levinson, 2003; Liu et al., 2004; Tilahun and Levinson, 2010). Specifically, reliability measures are studied for freeway corridors through empirical analysis and simulation approaches were also applied (Chen et al., 2000; Levinson et al., 2004; Rakha et al., 2006; Sumalee and Watling, 2008; Zhang, 2012). However, freeway corridors only encompass a portion of a real-life multimodal transportation network. A planning agency trying to evaluate the effect of various policies (other than freeways) may not be able to fully utilize such information to estimate the value of travel-time reliability savings on an overall network level. In the planning stage, agencies often are not ready to collect new data, but would like to utilize available resources to estimate travel time reliability using existing tools such as using the travel demand model; Hence, a framework to measure OD-based reliability to calculate network-wide reliability savings using available data will be very useful, and is currently lacking in the literature.

2.2. Data sources for modeling reliability

Data for reliability studies are usually obtained from surveys. Qualitative questionnaires were the first surveys used in reliability studies where respondents were asked to rank the foremost reasons of their path choice, including some reasons that were related to reliability (Chang and Stopher, 1981; Prashker, 1979; Vaziri and Lam, 1983). Then, gradually quantitative SP surveys became dominant in the field and were utilized in numerous studies (Abdel-Aty et al., 1997; Jackson and Jucker, 1982) is one example. In a path choice study, Abdel-Aty et al. (Abdel-Aty et al., 1997) offered two paths to the respondents; one with fixed travel time every day, and the other with a possibility that the travel time increases on some day(s). The results showed that males are more willing to choose uncertain paths. In the scheduling study of Small (Small, 1999), respondents were given two options with different travel time distributions and travel costs based on their preferred arrival time. Small (Small, 1999) found that unreliability had higher disutility for respondents with children and respondents with higher income. Some other studies (Koskenoja, 1996; Small et al., 2005) added nonlinearities in the scheduling models. SP surveys evolved later (Bates et al., 2001; Cook et al., 1999) showed how the presentation of travel time variability can have a significant impact on the estimation; their work was followed in different reliability studies (Asensio and Matas, 2008; Copley and Murphy, 2002; Hensher, 2001; Hollander, 2006; Tilahun and Levinson, 2010). While there are many examples of reliability studies using SP data in the literature, RP studies are limited. Carrion and Levinson (2012) related this scarcity to a lack of experimental settings showing significant difference among alternatives and costs associated with planning, deploying and gathering data from these surveys (Carrion and Levinson, 2012).

2.3. Valuation of travel time reliability

Value of Travel Time (VoT) and Value of Travel Time Reliability (VoTR) are two important parameters used in transportation planning and travel demand studies. VoT refers to the monetary value travelers place on reducing their travel time. Similarly, VoTR denotes the monetary value travelers place on reducing the variability of their