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Temporal and weather related variation patterns of urban travel time: Considerations and caveats for value of travel time, value of variability, and mode choice studies

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A B S T R A C T

By merging a large data set containing GPS records of taxi trips and historical weather records for New York City (NYC), the descriptive statistics of travel time (e.g. average travel time (ATT), standard deviation (SDTT), and coefficient of variation (CoV)) are calculated for each hourly period throughout the week and various weather conditions. Then, a Classification and Regression Trees methodology is used to determine the temporal patterns of ADTT, SDTT, and CoV, again for all time periods and weather conditions. Finally, the identified temporal patterns are discussed with respect to the findings and assumptions of value of time (VOT), value of reliability (VOR), and mode choice studies in the literature. The analysis shows that traditional peak hours are not necessarily the most congested periods and that the peak periods also exhibit inter-period heterogeneity in terms of ATT and SDTT. As opposed to ATT and SDTT, the coefficient of variation was shown to exhibit more consistent patterns among the days. In this respect, caution is advised for VOT–VOR studies regarding the temporal discrepancies in ATT and SDTT patterns; and CoV is suggested to be considered in VOT studies as a more robust measure. In terms of weather impacts, inclement weather is shown to have the potential to decrease SDTT and CoV at certain time periods, resulting in higher travel time reliability. This counter-intuitive finding is discussed with regards to traveler perceptions and possible implications on route and mode choice.

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1. Introduction

The travel time variation on road networks is mainly the result of recurrent congestion. In addition, non-recurrent events (incidents, weather, etc.) also create travel time variations. Researchers have investigated travel time variability for freeways and arterials using loop detector data, probe vehicles, Bluetooth devices, GPS records, electronic toll collection devices and similar technologies that can track vehicles in the road network. The findings are used to model route choice on road networks and analyze the mode choice with additional input from transit travel time variability. Travel time variability is also suggested as a measure for level of service (Chen et al., 2003), cost-benefit analysis (Taylor, 2009), regional transportation planning improvements (Lyman and Bertini, 2008), and policy and investment decisions (Van der Waard, 2009). Following

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the increasing interest in travel time variability and reliability, researchers started studying *value of travel time variability/reliability* (VOR) alongside *value of time* (VOT). As an additional measure, the reliability ratio ($RR = \frac{VOR}{VOT}$) is also introduced. The studies on VOT and VOR mainly employ expected/random utility theory and stated/revealed preference surveys to assign a monetary value to travel time and its variability.

Intuitively, VOT and VOR should be different for peak periods with scheduling constraints (i.e. making it on time for work) compared to off-peak periods with fewer or no scheduling constraints. VOT and VOR are basically the marginal rates of substitution between the travel cost and travel time and variability. In this respect, the *varying* magnitude and standard deviation of travel times at particular time periods are expected to affect the monetary values attributed to the travel time saving. VOT/VOR studies are generally conducted for AM-peak periods (Carrion and Levinson, 2012). As discussed in Wardman and Inabez (2012), the traffic conditions affect travelers' VOT and studies need to consider more than simple congested–uncongested traffic dichotomy. They suggest congestion multipliers that reflect the impact of congestion levels on value of travel time savings. Hence, identifying periods with consistent travel time characteristics can help re-assess the estimated VOT and VOR values for different time periods.

Moreover, the travel choices in the surveys are stated within "laboratory conditions", so to speak, by giving several hypothetical route choices with accompanying travel time, variability, and cost. Hence, the travelers' real life perceptions of a particular route at a particular time are generally ignored. Carrion and Levinson refer to the actual travel time for a route as objective travel time and the travelers' perception as subjective travel time. On one hand, referring to the psychology studies, they discuss that accumulated previous experience would provide a basis for one's expectation for the duration of a certain task (Carrion and Levinson, 2013). A well-informed, frequent traveler can be assumed to have a *good* estimation of the travel time and value their travel time savings. On the other hand, Carrion and Levinson report that this is not necessarily the case (Carrion and Levinson, 2013). Perception errors in self-reported travel times are prone to invalidate the calculated VOT and VOR values. The travelers can be wrong about the *level* of average travel time and variation, e.g. higher actual travel time than self-reported times, or they can have completely incorrect perceptions, e.g. expecting higher travel time variation whereas actual conditions indicate lower variation. Such errors can be fully studied *only* with data covering *both* the actual and perceived travel times. However, such data are very scarce and may not exist for many locations. Actual travel time records are relatively easier to obtain, and the literature also includes studies on travelers' perceptions. In this sense, comparison of anticipated and actual travel time patterns may help identify the discrepancies.

Meanwhile, as a future research direction, Carrion and Levinson (2013) suggest focusing on the influence of external sources of information on the magnitude of VOT and VOR. Although referred to as non-recurrent events in the literature, weather conditions are different from other non-recurrent events (i.e. incidents) by the fact that they are relatively predictable and travelers can have advance-notice of them through weather forecasts. It may be overreaching to say that weather impacts on travel time variability would have long term implications. Nonetheless, travel time variability is used for studying short-term route choice in transportation networks (Liu et al., 2004; Tilahun and Levinson, 2006; Abdel-Aty and Abdalla, 2006; Hainen et al., 2011) as well. Weather conditions can also affect the travel time perceptions of travelers and may play an important role in day-to-day mode choice decisions (Khattak and De Palma, 1997; Sumalee et al., 2011; Eluru et al., 2012). Overall, quantifying the actual weather impacts on travel time variability can help uncover the influence of weather information on VOT and VOR, and can be further used in route-mode choice models.

Considering the issues discussed above, the current study objectives are to:

1. Report the average travel time and travel time variation characteristics in New York City for all time periods and all days of the week (24/7).
2. Quantify the weather impacts on travel time and variability.
3. Identify temporal periods that exhibit similar travel time characteristics.
4. Identify the discrepancies between the *generally anticipated* and actual travel time patterns, and discuss potential caveats for VOT, VOR, and mode choice studies.

The study of actual travel time distributions is not new, however the existing studies mainly focus on certain days of the week and time of day periods and the sample sizes are relatively small. The recent higher market penetration of GPS devices makes it possible for a vehicle to function as a probe vehicle and to provide accurate documentation of travel times. There are almost 13,000 taxis with a GPS device in New York City (NYC) working 24/7. The current study uses GPS records of taxi trips with more than 370 million records covering a period of 18 months to calculate the travel time distributions in the urban network of NYC. Such a large data set offers very large sample sizes for all time periods and allows a detailed analysis of weather conditions.

The outline of the current paper is as follows. First, a literature review on VOT/VOR and existing studies on actual travel time distributions is presented. Second, the data employed for the current study is described in detail, followed by the descriptive statistics of travel time for all day-of-week (DOW) and time-of-day (TOD) periods along with the weather impacts. Third, a Classification and Regression Trees (C&RT) methodology is used to determine the periods that exhibit similar average travel time and travel time variance characteristics. Finally, the possible implications of findings on VOT/VOR and mode choice are discussed and summarized.