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Investigating empirical implications of hysteresis in day-to-day travel time variability

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ABSTRACT

Day-to-day travel time variability plays a significant role in travel time reliability. Nowadays, travelers not only seek to minimize their travel time on average, but also value its variation. The variation in the mean and the variance of travel time (across days, for the same departure time) has not been thoroughly investigated. A temporary decrease in capacity (e.g. congestion caused by an active bottleneck) leads to a quite significant difference in the variance of travel time for congestion onset and offset periods. This phenomenon results in hysteresis loops where the departure time periods in congestion offset exhibit a higher travel time variance than the ones in congestion onset with the same mean travel time. The aim of this paper is to identify empirical implications that yield to the hysteresis phenomenon in day-to-day travel times. First, empirical hysteresis loop observations are provided from two different freeway sites. Second, we investigate the potential link with the hysteresis observed in traffic networks on macroscopic fundamental diagram (MFD). Third, we build a piecewise linear function that models the evolution of travel time within the day. This allows us to decompose the problem into its components, e.g. start time of congestion, peak travel time, etc. These components, along with their probability distribution functions, are employed in a Monte Carlo simulation model to investigate their partial effects on the existence of hysteresis. Correlation among critical variables is the most influential factor in this phenomenon, which should be further investigated regarding traffic flow and traffic equilibrium principles.

1. Introduction

Nowadays, there has been a growing interest in understanding travel time variability to make decisions such as route choice and departure time. Recent studies (Hollander, 2006; Asensio and Matas, 2008; Li et al., 2010) show that people value both travel time and its predictability to choose their paths. In addition, researchers investigate the effect of travel time reliability in the scheduling of activities with respect to earliness or lateness cost (see for example Fosgerau and Karlstrom, 2010; Brownstone and Small, 2005). Regarding this aspect, travel time reliability, a performance indicator of roadways, has an important effect on route and departure time choice, especially for time constrained trips (e.g. commute to work, trip to airport).

Travel time variability, which develops the formal basis for reliability measures, can be investigated from several angles: vehicle-to-vehicle variability which corresponds to different vehicles traveling the same route at the same time, period-to-

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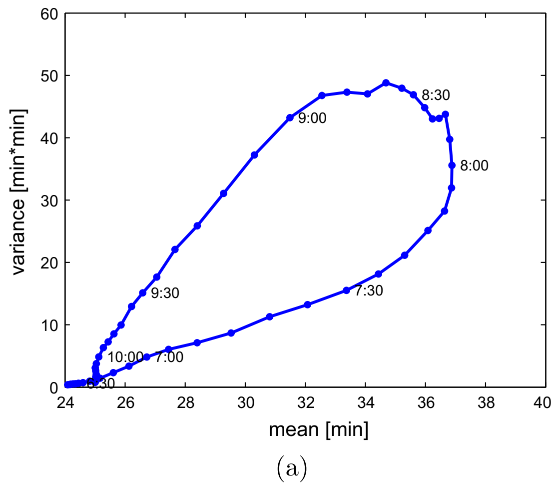
period variability corresponding to vehicles traveling the same route at different periods within a day, and day-to-day variability addressing the travel time variations of vehicles crossing the same route at the same period of time on different days (Noland and Polak, 2002). An accurate travel time reliability model might need to recognize these different types of variability at various levels. For instance, Kim and Mahmassani (2014) propose a compound distribution approach that distinguishes between day-to-day and vehicle-to-vehicle variability in modeling travel time reliability. However, they approximate the relation between mean and variance in day-to-day travel time distribution by a linear curve. In this paper, we further investigate this relation that cannot be easily captured by a linear curve (see Fig. 1) and identify empirical implications that lead to counter-clockwise 'hysteresis' loops. Note that details related to Fig. 1 are later given in the text. Bates et al. (2004) is the first study to the authors' knowledge that investigates the relation between mean and variance in day-to-day travel times. They observe hysteresis loops in a single link and single bottleneck study area. This phenomenon results in counter-clockwise loops where the departure time periods in congestion offset exhibit a higher travel time variance than the ones in congestion onset with the same mean travel time.

Hysteresis in traffic domain has been first defined by Edie (1963) and Treiterer and Myers (1974) as the separation between acceleration and deceleration curves in speed-density diagrams. Asymmetric theories that provide explanations for the mechanisms of hysteresis are described in Newell (1965), Zhang (1999), Yeo and Skabardonis (2009) and others. Nevertheless, traffic hysteresis loop may disappear when lane-observed data are aggregated in 1–5 min intervals (Daganzo, 2002). The same reference attributed the hysteresis phenomenon to lane changing and the non-conservative nature of flow in a single lane. Hysteresis is also observed at the network level; Geroliminis and Sun (2011a) investigates the causes of the hysteresis in macroscopic fundamental diagram (MFD), where higher network flows are observed for the same network density in the onset and lower in the offset of the congestion. According to Geroliminis and Sun (2011a), the hysteresis phenomenon in the network level happens because of two reasons. The first reason is that distributions of individual occupancy measurements (congestion distribution) are different for the same level of network density, see also Geroliminis and Sun (2011b). The second reason is the synchronized occurrence of transient states and capacity drop at the individual detectors. Similar hysteresis loops are identified in Buisson and Ladier (2009) and Saberi and Mahmassani (2012) with empirical observations in different freeway systems. Saberi and Mahmassani (2012) explore also the relationship between size of the hysteresis loop and inhomogeneity of the congestion distribution. Gayah and Daganzo (2011) test the effects of driver adaptivity on MFD hysteresis loops in a simplified two-bin network. Daganzo (2011) provides theoretical explanation for traffic instabilities in freeway systems and proposes driver adaptation as a solution to this type of capacity loss during recovery of congestion.

In this paper, we investigate the properties of hysteresis, and identify empirical implications that produce this phenomenon in day-to-day travel time distribution. These reasons are twofold in nature; due to network properties (i.e. traffic dynamics) and due to demand patterns. Fosgerau (2010) provides a theoretical proof for counter-clockwise loop using Vickrey bottleneck model with random service rate and assuming Nash equilibrium in arrival times. The equilibrium state in this model dictates a concave cumulative arrival function or an arrival rate which is decreasing. This implies a particular demand pattern in traffic networks and enables the theoretical proof of hysteresis loops in day-to-day travel times. However, empirical implications of hysteresis and which observed traffic variables influence the size of hysteresis loops are still not clear. On the other hand, Gayah et al. (2013) analyzes micro-simulation data and suggests that hysteresis behavior in day-to-day travel times is linked to the hysteresis loops observed in macroscopic fundamental diagram (MFD). It is, therefore, a network property. Note that hysteresis loops in travel time differs from the one in MFD in the sense that variability is computed across time, not across space. However, analytical travel time model developed in Gayah et al. (2013) does not explicitly account for the hysteresis in MFD, and therefore it is not possible to remove the MFD hysteresis from the model



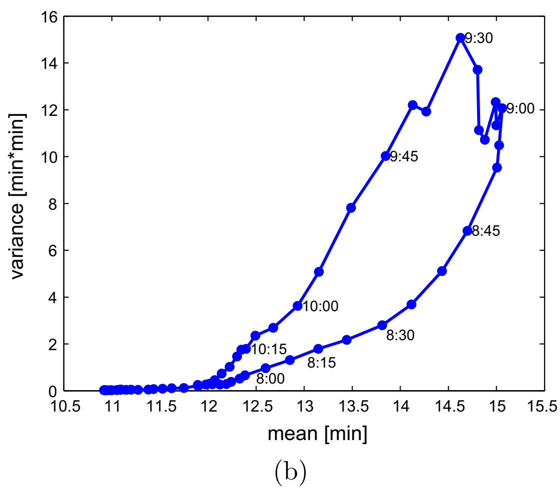


Fig. 1. Mean–variance curve in the morning peak period (a) in I-5S, and (b) in Attiki Odos.