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Understanding the mechanism of traffic hysteresis and traffic oscillations through the change in task difficulty level

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ABSTRACT

This paper provides a detailed understanding of the mechanism of traffic hysteresis and traffic oscillations from the driver behavior perspective. Microscopic evaluation of trajectories inside seven selected oscillations is performed to obtain a comprehensive picture of these puzzling phenomena. A new method based on driver's task difficulty (TD) profile is proposed to capture changes in driver behavior in response to the disturbance caused by traffic oscillations. A close connection between the TD profile and evolution (such as formation and growth) of the stop-and-go traffic oscillations is found. Furthermore, driver behaviors inside the oscillations are identified based on driver's TD profile, and their connection with hysteresis magnitudes is established. Finally, a generalized linear model suggests that variables related to traffic flow and driver characteristics are significant predictors of hysteresis magnitude. One noteworthy finding is that, the bigger the difference between the average TD levels between deceleration and acceleration phases of a vehicle trajectory, the larger the hysteresis magnitude becomes.

1. Introduction

Stop-and-go traffic oscillation is commonly observed during congested traffic and can have various adverse impacts including increased crash risk (Zheng et al., 2010; Zheng 2012) and reduced fuel efficiency (Bilbao-Ubillos, 2008). Caused by the retarded recovery of speed in the deceleration-acceleration process (Ahn et al., 2013; Chen, 2012), traffic hysteresis is an inseparable part of traffic oscillation. As both the phenomena are intertwined with each other, they are discussed side by side in this paper.

Several theories and models have been proposed to explain traffic hysteresis and oscillation (Gayah and Daganzo, 2011; Newell, 1965; Zhang, 1999; Zhang and Kim, 2005). See Laval and Leclercq (2010) for an excellent review on relevant notable efforts. However, the triggering driver behavior underlying these phenomena received little attention. There are a few exceptions. Among them, Yeo and Skabardonis (2009) conjectured that human errors (e.g., maneuvering errors) and anticipative behaviors might be associated with the origin and propagation of stop-and-go oscillation. However, the relationship between human errors and traffic oscillation was not investigated. Deng and Zhang (2015) explored the impact of driver

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relaxation and anticipation on traffic flow and numerically showed how the relaxation and anticipation can reproduce positive, negative, and double hysteresis loops. Wei and Liu (2013) reported that asymmetric driving behavior at deceleration and acceleration phases is likely to create hysteresis loops. After observing the fact that the follower's trajectory in a congested region deviates from the perfect follower created by Newell's (2002) model, Laval and Leclercq (2010) proposed that traffic oscillations, with which traffic hysteresis is usually associated, may have a strong connection with aggressive and timid driver behavior. Their findings were confirmed by Zheng et al. (2011b) and Chen et al. (2012, 2014) with empirical evidences. Despite the fact that many important properties of hysteresis and oscillation are discovered from these efforts, aggressive-timid categorization using pure trajectory data based on the deviation from the equilibrium spacing can induce false positive errors, which makes ensuing analysis less reliable. For example, there may exist many reasons (e.g., distraction) that bring a driver to the preceding vehicle closer than the equilibrium spacing, which does not necessarily confirm an aggressive behavior. Furthermore, in some cases, the same drivers are reported to change from aggressive into timid behavior (and vice versa) within short time interval. Such sudden change is hard to be justified and explained because in the behavioral research the aggressive/timid driving is well known to be closely related to the driver's personal traits, which is relatively stable over time. For example, Deffenbacher et al. (2003) reported that aggressive drivers tend to engage in risky behavior, even when they are not angry.

Although the bulk of the evidence suggests that hysteresis and oscillation are closely related to driver behavior, overall, our understanding of these puzzling phenomena remains elusive. Specifically, no established driver behavioral model is applied to understand these phenomena. Most of the conjectures about the relationship between driver behavior and the formulation/evolution of hysteresis and oscillation are proposed after an extensive analysis of the vehicle trajectory data. In other words, the conjectures are post hoc and data driven, and thus prone to narrative fallacy (offering a plausible explanation after the occurrence of an event; see Taleb (2010) for an excellent discussion on narrative fallacy, and its causes and consequences). Moreover, engineering CF models (models that use Newtonian laws of motion to describe CF behavior) are used to understand and reproduce hysteresis and oscillation. These models are criticized for not explicitly considering human factors (see Saifuzzaman and Zheng, 2014 for a discussion on this issue). Thus, Engineering CF models are inherently not suitable for investigating phenomena closely related to driver behavior such as hysteresis and oscillation. It could be possible to achieve small calibration errors by fine tuning model parameters; however, besides the potential over-fitting issue, the underlying behavioral insights triggering hysteresis and oscillation cannot be traced back from these models.

On the other hand, there are theoretical models proposed to explicitly explain human driving behaviors. Among them, the Task capability Interface Model (TCI, Fuller, 2002, 2005) is well-known for its capability of explaining driver's decision making mechanism using two basic concepts: task demand and driver capability. Specifically, when task demand is lower than driver capability, driving task is easy and within driver's control; when task demand exceeds driver capability, the task is difficult and can lead to collision. In TCI model, a driver continuously makes real-time decisions and adjustments to maintain the perceived difficulty of the driving task within certain acceptable boundaries (Fuller, 2002, 2011). Therefore, the key element of this model is the task difficulty (TD) that captures the dynamic interaction between driving task demand and driver capability and motivates driver's decision making. In our recent paper (Saifuzzaman et al., 2015b), inspired by TCI a Task Difficulty Car-Following (TDCF) framework has been developed to incorporate human factors into CF modelling and to better explain human decision making during a CF process. The TDCF framework has been applied to two mainstream CF models: Gipps' model and IDM, and satisfying performances have been achieved. Particularly, it has been confirmed that TD can be incorporated in engineering car-following models to better reflect human factors' role in CF behavior. Along the same lines, the underlying behavioral reason behind traffic hysteresis and the formation and propagation of traffic oscillation can be better explained by the changes in the difficulty level of the driving task the driver is facing. The perceived risk of the driving task prompts the driver to modify his/her behavior so that the perceived task difficulty level remains within the acceptable limit. For example, after experiencing a sudden deceleration (i.e., a task with a high difficulty level) a driver may proceed more cautiously in the acceleration phase (e.g., adopting a larger time headway) to maintain a lower level of task difficulty to avoid/minimize the need of future sudden decelerations. Thus, the acceleration behavior becomes different from the deceleration behavior, and this asymmetric behavior is likely to create a hysteresis loop. Note that such asymmetric behavior has been reported and linked to hysteresis in the literature based on empirical evidences without a formal behavioral theory (e.g., Newell, 1962, 1965; Yeo and Skabardonis, 2009). More discussion on this issue is presented later.

Hence, inspired by the important recent discovery that driver behaviors (e.g., aggressive/timid driving behavior) significantly contribute to traffic hysteresis and oscillation (Laval and Leclercq, 2010), this paper aims to provide a more solid foundation to the connection between driver behaviors and traffic hysteresis and oscillation by resorting to a well-established psychological/behavioral theory (i.e., TCI). The objective of this paper is to understand the mechanism of traffic hysteresis and traffic oscillations through the change in driver's TD level over the driving course, and also reveal driver behaviors inside an oscillation based on the driver's TD profile, and explore their connection with hysteresis magnitudes. To achieve this goal, seven fully developed oscillations have been selected from heavily congested traffic. They are investigated in detail to get a deeper understanding of the development and propagation of traffic oscillation and associated hysteresis behavior.

The rest of the paper is organized as follows: Section 2 describes the data and methodologies; Section 3 gives a detailed analysis of traffic oscillation and hysteresis properties; and finally, Section 4 discusses main findings and limitations of the study.