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Effects of congestion on drivers' speed choice: Assessing the mediating role of state aggressiveness based on taxi floating car data

Yizhe Huang[a,b], Daniel (Jian) Sun[a,c,*], Li-Hui Zhang[d]

[a] State Key Laboratory of Ocean Engineering, School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China
[b] Institute for Transport Planning and Systems, ETH Zurich, Zurich, 8093, Switzerland
[c] China Institute of Urban Governance, Shanghai Jiao Tong University, Shanghai, 200240, China
[d] Institute of Transportation Engineering, Zhejiang University, Hangzhou, 310058, China

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ABSTRACT

Inappropriate cruising speed, such as speeding, is one of the major contributors to the road safety, which increases both the quantitative number and severity of traffic accidents. Previous studies have indicated that traffic congestion is one of the primary causes of drivers' frustration and aggression, which may lead to inappropriate speed choice. In this study, the large taxi floating car data (FCD) was used to empirically evaluate how traffic congestion-related negative moods, defined as state aggressiveness, affected drivers' speed choice. The indirect effect of traffic delay on the cruising speed adjustment through the state aggressiveness was assessed through the mediation analysis. Furthermore, the moderated mediation analysis was performed to explore the effect of driver type, value of time, and working duration on the mediation role of state aggressiveness. The results proved that the state aggressiveness was the mediator of the relationship between travel delays and driving speed adjustment, and the mediation role was different across various driver types. As compared to the aggressive drivers, the normal drivers and the steady drivers tended to behave more aggressively after experiencing non-recurrent congestion during the early stage of the trips. When the value of time was high, steady drivers were more likely to adjust their speed choice although the effect was not statistically significant for other driver types. The validation results indicated that the speed model incorporating state aggressiveness could better predict the travel time than the traditional speed model that only considering the specific expected speed distribution. The prediction results for the manifest indicators of state aggressiveness, such as the maximum speed and the speed deviation, also demonstrated a reasonable reflection of the field data.

1. Introduction

For a long time, speed has become one of the major contributors to road safety, and inappropriate cruising speed, such as speeding, inevitably increases the quantitative number and severity of traffic accidents. In the United States, speeding was listed as a contributing factor in nearly one-third of fatal crashes from 2002 to 2011 (National Center for Statistics and Analysis, 2013). Nearly three-quarters of drivers reported that they had driven over the speed limit within the past month (Royal, 2003). In China, more than 90,000,000 speeding offenses were recorded in 2012 and over 7000 victims were dead from speeding-related crashes during the year (Traffic Management Bureau, 2012). Consequently, it is important to understand and predict the speed choice among drivers. Numerous studies have explored the situational determinants of drivers' speed choice, such as road attributions (Giles, 2004; Huang et al., 2018; Yagar and Van Aerde, 1983), traffic conditions (Huang et al., 2018), vehicular parameters (Giles, 2004), and time of day (Oppenlander, 1966; Richard et al., 2013). While these surveys mainly aimed to figure out the exogenous reasons for the speed choice of drivers, it is necessary to quantify how these factors affect the speed choice, so as to predict the speed selection from the psychological process of drivers.

Traffic congestion is one common exogenous source of frustration and aggression (Shinar, 1998; Shinar and Compton, 2004; Cœugnet et al., 2013; Szollos, 2009), which has been frequently overlooked by speed choice studies. According to Cœugnet et al. (2013), congestion-related travel delay can lead to tight time constraints and high time uncertainty, which are two main causal factors for time pressure. Numerous studies have indicated that time pressure is one of the most important factors affecting drivers' speed choice. In a national survey of speeding attitudes and behaviors, the most frequent reason for speeding was "being in a hurry" (Schroeder et al., 2013). The similar conclusion

* Corresponding author at: A829, Ruth Mulan Chu Chao Building, No. 800 Dongchuan Road, Shanghai, 200240, China.
E-mail addresses: huangyz@sjtu.edu.cn (Y. Huang), danielsun@sjtu.edu.cn (D.J. Sun), lihuizhang@zju.edu.cn (L.-H. Zhang).

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was found in McKenna (2005) that those who claimed frequently exceeding speed limit reported that the time pressure played a significant role in their speed choice. When drivers are under high time pressure, they are more likely to change lanes and increase speeds that can shorten their journey time as much as possible (Tarko, 2009; Peer and Rosenbloom, 2013). A simulator study found that compared to normal drivers, very hurried drivers tended to select higher speeds, accelerate faster after red lights, and accept smaller gaps on left turns (Fitzpatrick et al., 2017). They were more likely to overtake a slow vehicle and run a yellow light (Fitzpatrick et al., 2017). Stern (1998, 1999) first introduced time pressure to explain the dynamics of driver state and choice under different conditions of congestion. Stern (1998) found that when under congestion-related time pressure, many drivers attempt to improve speeds on later sections of the trip. However, Stern (1998, 1999) did not empirically investigate the speed choice after congestion but rather stated behavior response.

After Stern (1998, 1999), few studies have focused on the effect of traffic congestion on drivers' en-route choice empirically, especially for speed choice. The major reason is the scarcity of reliable driver behavior-related data. The data sample required to identify and model the speed preference/choice triggered by congestion needs to be sufficiently massive, owing to the randomness of driver state (Hess and Train, 2011). Traditional methods, like traffic survey (Hennessy and Wiesenthal, 1997; Dahlen et al., 2012) and driving simulation (Stern, 1999; Danaf et al., 2015) have limitations to incorporate enough driver sample and represent the real world. Within the last decade, the wide usage of GPS devices allows traffic engineers to collect tremendous amounts GPS derived speed data with high time and space resolution. Some studies have demonstrated the advantages of introducing GPS data into traffic safety research (Huang et al., 2018; Wang et al., 2015), named as floating car data (FCD) method. Compared to the survey studies and driving simulator methods, which were frequently used in the speed-safety research, the FCD method assists to capture the en-route choice of drivers in more details and can represent drivers' speed choice under real scenarios.

1.1. State-trait theory

The state-trait theory, first introduced by Cattell and Scheier (1961), points out that the emotional experience of human being can be divided into two parts: a transient mood state and a long-term trait. The theory has been shown especially useful in anxiety research (Spielberger et al., 1983, Spielberger, 1988) and has been widely applied to aggressive driving research since Deffenbacher et al. (1994). The state of driver can be described as emotional feelings of drivers, such as anger or excitement, which can reflect the intra-personal heterogeneity of drivers under different conditions. The trait of driver can be described as a long-term tendency of drivers, such as driving style and the characteristics of drivers, which can reflect the inter-personal heterogeneity of drivers. To date, it has been repeatedly shown in the literatures that both the trait of a driver and the state of a driver have strong relationships with aggressive driving behaviors (Hennessy and Wiesenthal, 1997; Dahlen et al., 2012; Danaf et al., 2015; Shinar, 1998; Shinar and Compton, 2004; Peer, 2010; Peer and Rosenbloom, 2013; Tseng, 2013; Huang et al., 2018). Hennessy and Wiesenthal (1997) applied the state-trait theory to explain the relationship between traffic congestion, driver stress and coping behaviors of drivers. To empirically test and quantify this relationship, this paper applies the state-trait theory by including driver state and driver type to account for the effect of congestion on drivers. The congestion-related negative mood is defined as state aggressiveness, which was investigated in detail in Section 2.3.1.

When drivers experience heavy congestion condition, they are more likely to exhibit elevated levels of stress, including frustration, irritation, and other negative moods (Hennessy and Wiesenthal, 1997; Hennessy and Wiesenthal, 1999; Underwood et al., 1999; Feng et al., 2016). In a phone survey, Hennessy and Wiesenthal (1997) found that drivers' level of state stress and aggression in heavy congestion were higher than mild congestion. Using driving anger scale (DAS), Feng et al. (2016) found that traffic congestion was the most anger provoking of the four driving anger subscales for professional drivers in China. Similarly, Underwood et al. (1999) examined the diaries of 100 drivers and found that drivers were more likely to report angry when they were experiencing congestion. They also found that drivers who generally reported high congestion had no tendency to report more driving anger. This can be explained by Stern (1999), as congestion could generally be divided into recurrent congestion and non-recurrent one. Drivers would have less time pressure within recurrent congestion than non-recurrent one because they could arrange the preventive response in advance, such as leaving home earlier. In addition, Shinar and Compton (2004) mentioned that the value of time also played an important role in affecting the feeling of drivers. For example, when the value of time is high, e.g., rush hours, the traffic delay could be very frustrating. Drivers are more likely to drive aggressively during the rush hours than the periods with low value of time, such as non-rush weekdays or weekends. The effect of traffic congestion on the state of drivers and their speed choice may also have significant differences among drivers with various traits, such as cultural norms (Shinar, 1998), sensation-seeking (Peer and Rosenbloom, 2013), time-saving bias, trait stress (Hennessy and Wiesenthal, 1997), and trait anger (Danaf et al., 2015). These personality factors can be well reflected by drivers' daily habitual behavior, such as preferred speed, which was found to be one of the most important factors in predicting driving anger (Feng et al., 2016).

1.2. Aim and objective

The present study was to empirically analyze and quantify how did the traffic delay affect drivers' speed choice. The driving style and the state of driver were identified based on the large taxi FCD dataset in Shanghai. While the results of taxi drivers may not apply to the non-professional drivers, the approach proposed in this study can be used to investigate these drivers if the corresponding FCD data were available. Moreover, investigating the speed choice of taxi drivers is also important because taxi drivers tend to have more opportunities to be involved in a speed violation (Huang et al., 2018; Tseng, 2013).

More specifically, the main objective of the current study is to test and model the role of driver state aggressiveness and driver trait in the relationship between congestion-related delay on the first half of the trips and drivers' speed adjustment on the second half of the trips. The three sub-objectives are:

- To classify drivers into different driver types according to their habitual speeds in different traffic conditions.
- To test the mediation role of driver state aggressiveness when analyzing the influence of traffic delays on driver speed choice.
- To test and incorporate driver type, the value of time, and working hours through a moderated mediation process, so as to explain and predict drivers' speed choice with travel delays.

The remainder of the paper is structured as follows: Section 2 proposes the methods of classifying drivers along with the mediation analysis process and moderated mediation analysis process. Next, the model implementation and validation process are presented in Section 3. Section 4 discusses the results and demonstrates the limitations and the future work. Finally, conclusions are provided in Section 5.

2. Statistical methods

This section presents an empirical data-based approach to detect and model the mediation effect of state aggressiveness on the relationship between traffic congestion and drivers' speed choice on urban roads. The first step relates to the driver type classification,