Transportation Research Part C 67 (2016) 193–213

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Weather and road geometry impact on longitudinal driving behavior: Exploratory analysis using an empirically supported acceleration modeling framework

Samer H. Hamdar [a,*], Lingqiao Qin [b], Alireza Talebpour [c]

[a] Department of Civil and Environmental Engineering, Center for Intelligent Systems Research, The George Washington University, Science and Engineering Hall #3810, 800 22nd Street, NW, Washington, DC 20052, USA

[b] Department of Civil and Environmental Engineering, Traffic Operation and Safety Laboratory, University of Wisconsin – Madison, Engineering Hall #1249, 1415 Engineering Drive, Madison, WI 53706, USA

[c] Zachry Department of Civil Engineering, Texas A&M University, CVLB # 301E, 3136 TAMU, College Station, TX 77843, USA

ARTICLE INFO

Article history:
Received 1 May 2015
Received in revised form 23 January 2016
Accepted 28 January 2016

Keywords:
Car following
Driving simulator
Prospect Theory
Road geometry
Safety
Weather

ABSTRACT

The objective of this paper is to quantify and characterize driver behavior under different roadway geometries and weather conditions. In order to explore how a driver perceives the rapidly changing driving surrounding (i.e. different weather conditions and road geometry configurations) and executes acceleration maneuvers accordingly, this paper extends a Prospect Theory based acceleration modeling framework. A driving simulator is utilized to conduct 76 driving experiments. Foggy weather, icy and wet roadway surfaces, horizontal and vertical curves, and different lane and shoulder widths are simulated while having participants driving behind a yellow cab at speeds/headways of their choice. After studying the driving trends observed in the different driving experiments, the extended Prospect Theory based acceleration model is calibrated using the produced trajectory data. The extended Prospect Theory based model parameters are able to reflect a change in risk-perception and acceleration maneuvering when receiving different parameterized exogenous information. The results indicate that drivers invest more attention and effort to deal with the roadway challenges compared to the effort to deal with the weather conditions. Moreover, the calibrated model is used to simulate a highway segment and observe the produced fundamental diagram. The preliminary results suggest that the model is capable of capturing driver behavior under different roadway and weather conditions leading to changes in capacity and traffic disruptions.

1. Introduction and motivation

Environmental conditions have been identified to have major impacts on driver behavior. Examples of different environmental conditions are weather-related and roadway geometry-related factors. For instance, it has been shown that reduced visibility has a substantial impact on traffic flow dynamics (Hoogendoorn et al., 2010) while the geometry of the road layouts leads to changes in driving behavior (McLean, 1981). Moreover, weather condition and road geometry are the two congestion and crash triggering factors. Empirical evidence suggests that the likelihood of rear-end crashes increases during abnormal

* Corresponding author. Tel.: +1 (202) 994 6652; fax: +1 (202) 994 0127.
E-mail address: hamdar@gwu.edu (S.H. Hamdar).

http://dx.doi.org/10.1016/j.trc.2016.01.017

weather or at accident prone sections (Brackstone et al., 2009; Winsum, 1999; Knuiman et al., 1993; Karlaftis and Golias, 2002; Polus et al., 2005). However, little effort has been made to quantify their effects on driving behavior (in the micro scale) and congestion and safety (in the macro scale). Therefore, more detail behavioral bases studies are required to describe the driver behavior in different weather and roadway conditions.

Driver behavior is subject to change according to the surrounding environment. While it is expected that different driving environments impose different changes to the driving behavior of an individual, the magnitude of deviation from normal driving behavior varies among drivers. Comprehensive study of the effect of certain driving environments on driving behavior has been presented in the literature (Brackstone et al., 2009); however, little effort has been presented to quantify the effects of different weather conditions and road geometrical configuration on driving behavior. The main objective of this paper is to explore how a driver perceives the dynamic changing driving surroundings (i.e. different weather conditions and road geometrical configurations) and executes acceleration maneuvers accordingly. Specifically, this study presents an effort to quantify the changes in drivers' car-following behavior under different roadway geometries and weather conditions. Accordingly, this study presents an extension to the Prospect Theory based car-following model of Hamdar et al. (2008, 2015). Prospect Theory is commonly considered as one of the most powerful descriptive theories of human decision-making. Hamdar et al. (2008) has first put forward an acceleration model, which adopts Prospect Theory to reflect the psychological and cognitive aspects of the decision making process. In this Prospect Theory based acceleration model, time is divided into different acceleration instances, and at each time instance, driver may accelerate, decelerate or keep his or her current speed. In other words, drivers make decisions on acceleration choices, and their choices are based on an evaluation of gains and losses. This paper builds on this acceleration model that translates this utility-based concept into longitudinal driving behavior. The presented model extends the current Prospect Theory logic by considering the effect of the external driving environment while keeping the adopted probabilistic nature of human judgment. A driving simulator is used to test individual driving behavior in different environmental situations and then use the data obtained from the driving experiments to calibrate the micro acceleration model.

The structure of the remainder of this paper is as follows. First a background review on the effects of weather and road geometry on driver behavior is presented. This section is followed by the modeling framework and the related parametric sensitivity analysis. Experimental setup and data collection procedures are presented next followed by a thorough numerical analysis. The numerical results including the calibration results are presented next. The concluding remarks and the future research directions are presented last.

2. Background

This section presents a review of the literature focused on the impact of different weather and road geometry characteristics on driver behavior. Note that this section does not provide any background on car-following behavior and microscopic simulation models. A comprehensive study of these models can be found at Hamdar et al. (2008, 2015) and Talebpour et al. (2011).

2.1. Weather

Multiple studies have focused on the statistical relationships between different traffic measures and different surrounding weather conditions. The overall findings of these macro level studies denote that visibility impairment, precipitation, and temperature extremes may affect driver behavior and vehicle maneuverability. Chen et al. (1995) found that weather and road surface conditions bring about some differences in car-following behavior. Based on recorded traffic data, Ibrahim and Hall (1994) found that free-flow speed reduces 1.9 mph in light snow, 3.1–6.2 mph in heavy rain, and 23.6–31 mph during heavy snow. Liang et al. (1998) conducted a study to investigate the impact of visibility on speed. Through data collection, they found that average speed reduces 11.9 mph during snow events.

Another group of studies have focused on the concepts and theories of car following to understand drivers' car following behavior, their headway selection and how the choice of headway affects safety (Brackstone et al., 2009; Winsum, 1999). It was suggested that drivers' car following behavior can be affected in dense fog resulting from obscure scenery (Evans, 2004). Evans (2004) also observed that drivers tended to follow the lead vehicles much closer from the fear of losing a reference when driving in foggy weather. Hawkins (1988) reported a significant increase in distance headways when visibility distance was 150 m. Van Der Hulst et al. (1998) studied driving behavior in fog with a visibility distance of 150 m. They noted that due to the difficulty in anticipation, drivers increase time headway under low visibility conditions. They also found that drivers' reactions to decelerations of the leader were very accurate even at low visibility levels. Broughton et al. (2007) employed a high-fidelity driving simulator to measure the car-following behavior under three visibility conditions. Two distinctive driving styles were identified in their studies: laggers and non-laggers driving styles; the laggers stopped following the leader within visible distances and instead dropped back to some larger distance headways, accompanied by increases in speed variability, whereas the non-laggers remained in a true car following mode with a visible leader ahead of them. Hoogendoorn et al. (2010) also conducted a set of driving simulation experiments and suggested that fog led to a decrease in speed as well as in acceleration rate. A substantial increase in distance to the lead vehicle was also observed in the experiments.