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Comparisons of mandatory and discretionary lane changing behavior on freeways

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A B S T R A C T

This research performs comparative analyses on drivers' behavior during mandatory and discretionary lane changes. We do this by examining the statistical properties of four lane changing decision variables that describe the gaps between the subject vehicle and the surrounding vehicles. Mandatory and discretionary lane changes in NGSIM's I-80 Freeway and U.S. Highway 101 data collection sites were identified. First, for each variable at the same site, descriptive statistics for the two types of lane changes were compared, and hypothesis tests on the difference between two means were conducted. Then, for each decision variable at the same site, the observed cumulative distributions between the mandatory and discretionary lane changes were compared by means of the Kolmogorov–Smirnov test. This test was repeated for the fitted distributions of the same decision variable at the same site. The results show that, for the three decision variables associated with gaps in the target lane, the means and distributions between the two types of lane changes are not significantly different. The only variable found to have significant differences in means and distributions is the gap between the subject vehicle and the preceding vehicle in the original lane. This may be because this variable is not an important input in mandatory lane change decisions. This finding provides statistical justification for researchers to develop models with different inputs for mandatory and discretionary lane changes in driver assist systems, in autonomous vehicles, and in microscopic traffic simulation tools.

1. Introduction

Lane changing is one of the basic activities in freeway driving. Drivers change lanes so as to, among other reasons, gain speed or move into the correct lane in anticipation of the next turning movement downstream (Balal et al., 2016, 2014; Pan et al., 2016; Zheng, 2014). A lane change that is not executed in a safe manner may result in a rear end, side swipe, or angled crash (Romo et al., 2014). With the advent of connected and autonomous vehicles, a good understanding of drivers' lane changing behavior and the ability to model it under different conditions has critical impacts on the safety and capacity of autonomous driving on highways.

A lane change may be classified, depending on the driver's motivation, as mandatory or discretionary. A Mandatory Lane Change (MLC) usually occurs when the subject driver is trying to move his/her vehicle from its existing lane into the target

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lane in anticipation of the next left or right-turn, or lane closure immediately downstream. A Discretionary Lane Change (DLC) usually occurs when a driver desires a faster speed, greater following distance, further line of sight, better ride quality, etc. in the target lane (Balal et al., 2016, 2014; Pan et al., 2016; Zheng, 2014). Because of the different motives, the risk-taking behavior of a driver when executing MLCs and DLCs are believed to be different (Pan et al., 2016).

The objective of this research is to perform statistical comparisons of lane changing behavior between MLCs and DLCs. We used four gap values that describe the distances between the subject vehicle and the surrounding vehicles to represent the subject driver's risk-taking behavior. This research used NGSIM data collected at two sites: I-80 Freeway at Emeryville (Cambridge, 2005a) and U.S. Highway 101 in Los Angeles (Cambridge, 2005b), both in California. The objective is accomplished by the following four tasks that were applied to data extracted from each site:

(i) Examine the descriptive statistics for each lane changing decision variable for MLCs and DLCs, comparatively;
(ii) Conduct hypothesis tests on the difference between the means of MLCs and DLCs, for each decision variable;
(iii) Apply the Kolmogorov–Smirnov test (Ang and Tang, 2007), for each decision variable, to test the difference in the observed cumulative probability distributions between MLCs and DLCs;
(iv) For each variable, fit the probability distributions to the MLC and DLC data respectively, and use the Kolmogorov–Smirnov test to test the difference between the fitted probability distributions.

This article is organized as follows. After this introduction, issues related to the modeling of MLCs and DLCs are reviewed. The decision variables are defined. This is followed by a description of the data. The next section, which is the most important part of this paper, presents and discusses the results of statistical tests. This paper concludes by highlighting the findings, limitations, and contributions of this research.

2. Literature review

Comprehensive reviews of lane changing models have been made by Moridpour et al. (2010) and Zheng (2014), and subsequently summarized by Balal et al. (2016). Research articles on lane change mostly focus on MLC and/or DLC model development and applications for freeway driving. Very few papers compare the difference between MLCs and DLCs. Furthermore, no published literature has documented a quantitative study on the similarities and/or differences in driving behavior between MLCs and DLCs, with field data. This literature review focuses on the similarities and differences between MLC and DLC models.

2.1. Lane changing models in microscopic traffic simulation tools

There are two types of lane changes in FRESIM: free and forced lane change (FHWA, 1995). A free lane change is equivalent to a DLC, while a forced lane change is equivalent to an MLC. In FRESIM, both types of lane change use the same decision variables: *lead time to collision* and *lag time to collision* in the target lane. Both values must satisfy their respective "non-collision constraint."

VISSIM classifies lane changes into free lane change and necessary lane change, which are equivalent to DLCs and MLCs, respectively (PTV, 2007). The free lane change uses *lag time to collision* in the target lane as the decision variable. For necessary lane change, the model also checks the *lead time to collision* and *maximum deceleration*.

PARAMICS does not distinguish between MLCs and DLCs. The lane changing model in PARAMICS is based on the gap acceptance theory (Quadstone, 2009), which has *front gap* and *rear gap* (both in distance unit) in the target lane as the decision variables.

AIMSUN describes a vehicle's motivation to change lane in terms of necessity, desirability, and possibility to change lanes (TSS, 2002). The necessity to change lanes involves more than just MLC. In addition to the unclear mapping between the three motivations into MLCs and DLCs, AIMSUN divides a freeway segment upstream of an off-ramp into three zones, where DLCs take place in the most upstream zone.

TransModeler uses the discrete choice approach to model a driver's lane changing decision. It considers three types of lane change: discretionary, mandatory, and forced lane changes (Caliper, 2011). There are two DLC models: neighboring lane model and target lane model. They use utility functions consisting of different attributes.

2.2. Other lane changing studies

Gipps (1986) proposed a lane-changing model encompassing MLCs and DLCs. The decision variables for DLCs included the subject vehicle's safe *speed*, *relative speed* between the original lane and the target lane, and *time to collision* between preceding and following vehicle in the target lane.

Wu et al. (2000) described different motivations for lane change: pressure from the rear (fast approaching vehicle) and to gain *speed*. They did not distinguish between MLCs and DLCs.

Zheng (2014) suggested the need to develop a framework that encompasses MLC and DLC decision making processes. This is followed by Pan et al. (2016) who proposed a mesoscopic cell transmission multilane freeway model that incorporated

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