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Socio-demographic impacts on lane-changing response time and distance in work zone with Drivers' Smart Advisory System

Qing Li, Fengxiang Qiao, Lei Yu*

Department of Transportation Studies, Texas Southern University, Houston, TX 77004, USA

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ABSTRACT

Lane-changing behavior is an important component of traffic simulation. A lane-changing action is normally confined to a decision-making process of the task, and the action itself is sometimes assumed as an instantaneous event. Besides, the lane-changing behavior is based mostly on observable positions and speeds of other vehicles, rather than on vehicles' intentions. In practice, changing one lane requires about 5–6 s to complete. Existing lane-changing models do not comprehensively consider drivers' response to work zone lane-changing signs (or other related messages, if any). Furthermore, drivers' socio-demographics are normally not taken into account. With regard to this, fuzzy logic-based lane-changing models that consider drivers' socio-demographics were developed to improve the realism of lane-changing maneuvers in work zones. Drivers' Smart Advisory System (DSAS) messages were provided as one of the scenarios. Drivers' responses, including reactions to work zone signs and DSAS messages, and actions to change lane, were investigated. Drivers' socio-demographic factors were primary independent variables, while Lane-Changing Response Time (LCRT) and Distance (LCRD) were defined as output variables. The model validation process yielded acceptable error ranges. To illustrate how these models can be used in traffic simulation, the LCRT and LCRD in work zones were estimated for five geo-locations with different socio-demographic specifications. Results show that the DSAS is able to instruct all drivers to prepare and change lanes earlier, thereby shortening the duration of changing lanes. Educational background and age are essential variables, whereas the impacts of gender on the output variables are indistinctive.

* *Corresponding author*. Tel.: +1 7133131915; fax: +1 7133131856.
E-mail addresses: liq@tsu.edu (Q. Li), qiao_fg@tsu.edu (F. Qiao), yu_lx@tsu.edu (L. Yu).

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1. Introduction

Driver behavior is one of the most fundamental components in microscopic traffic simulation, which is a dynamic modeling of individual vehicle's movements on a second or sub-second basis. The modeling could be used to assess the traffic performance on highway and street systems, in transit, and among pedestrians (FHWA, 2004). Transportation modeling and simulation have been widely applied in transportation engineering and planning practices, such as the capacity analysis, traffic impact study, junction design, accident analysis, network analysis, etc. (Ranjitkar and Nakatsuji, 2005). Meanwhile, a number of formulated models of traffic flow have been applied to simulate more realistic driver performance (Chandler et al., 1958; Liu et al., 2006).

Car following and lane-changing behaviors are two determinants the design of microscopic traffic simulation models. While car-following models are concerned with the travel time and space between two consecutive vehicles in the same lane, and simulate the motion of lag cars (Pipes, 1953), lane-changing models depict the distribution of vehicles across lanes (Rorbech, 1976). Compared to car following studies, lane-changing behavior is more complicated because it involves three elements, the need to change lanes, the possibility of changing lanes, and the trajectory for changing lanes (Hwang and Park, 2005). When a driver must leave the current lane following a specified path, Mandatory Lane-Changing (MLC) is expected to follow. Discretionary Lane-Changing (DLC) is just intended to improve driving conditions, such as achieving the desired speed, avoiding following trucks or merging traffic, etc., but the action to change lanes is not absolutely necessary (Toledo et al., 2003).

Gipps (1986) proposed a lane-changing model adopted in micro-simulation tools, which has taken into account the necessity, desirability, and safety of lane-changes in various urban driving situations. Subsequently, many lane-changing models capturing MLC and DLC situations have been evolved for realistic traffic simulation experiment results. For instance, Ahmed (Ahmed et al., 1996; Ahmed, 1999) developed and estimated the parameters of the target lane and gap acceptance models; Kita (1993) employed a logit method to formulate a gap acceptance model for merging sections of freeways; Yang and Koutsopoulos (1996) demonstrated a 'rule-based' lane-changing model for freeways. Several micro-simulation tools simulate lane-changing behaviors based on the Gipps' model, such as CORSIM (FHWA, 2007), MITSIM (Yang and Koutsopoulos, 1996), SITRAS (Hidas and Behbahanizadeh, 1999).

Lane changes in work zones involve merging sections that require MLC, which is the primary cause of the majority of conflicts and interactions among vehicles at merging sections. Existing traffic models are normally designed for conventional traffic control situations, such as signalized intersections, stop signs, and freeways. Along with the development of the Intelligent Transportation System (ITS), Vehicle-to-Infrastructure (V2I) wireless communication technologies have been introduced to improve drivers' awareness (Lin et al., 2013). The Drivers' Smart Advisory System (DSAS) is one of such emerging technology to enhance communication between vehicles and temporary work zone control devices for safety and better air quality purposes (Qiao et al., 2014).

Besides, existing models of lane change emphasize decision-making aspects of the task, regardless of the response itself. All kinds of lane changes are assumed as instantaneous events (Toledo and Zohar, 2007). However, it may take a few seconds to complete one lane change. The maneuvers reflect the driver's thinking process, in which the driver's individual characteristics play a crucial role for the level of acceptance on a particular DLC, minimum or maximum acceleration/deceleration adopted, etc. (Sun, 2009). Toledo and Zohar (2007) and Sun (2009) modeled lane-changing behaviors considering driver characteristics in terms of personal perception, maneuvers attitude, driver aggressiveness, and level of the likelihood of changing lanes. Actually, drivers' individual socio-demographic factors (e.g. gender, age, educational background, and driving experience) are essential variables in driving performance as well (Nauert, 2011).

Li and Qiao (2014) also clearly verified that socio-demographic factors may affect driving performance significantly when DSAS was provided, in terms of steady speed, brake response time, and brake distance. Such impacts of socio-demographic factors on lane-changing models, including lane-changing time and lane-changing distance, have not really been explored to date, especially when work zones have been equipped with V2I communication.

The objective of this research is to develop lane-changing models for microscopic traffic simulation, including the Lane-Changing Response Time (LCRT) model and the Lane-Changing Response Distance (LCRD) model. Fuzzy logic-based lane-changing models are developed specifically for MLC in work zones equipped with DSAS. We also investigate the impacts of socio-demographic factors on these lane-changing models.

2. Defining lane-changing response time and distance

Universally in microscopic traffic simulation, a lane-changing action is assumed as an instantaneous event. Nevertheless, a number of lane-changing studies have demonstrated that this assumption contradicts research findings in the area of human factors (Toledo and Zohar, 2007). Drivers' decision making and the execution process of lane changing require time and travel distance. Appropriate modeling of lane-changing related with time and distance would improve the realism of simulated experimental results.

2.1. *Existing lane-changing time methods*

Even though various studies have illustrated that one lane-changing action requires an average time of 5–6 s (Worrall and Bullen, 1970), there are discrepancies in lane-changing time that can be interpreted by some drawbacks in the estimation procedure and methodology, such as not