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Modeling driver behavior in dilemma zones: A discrete/continuous formulation with selectivity bias corrections

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ABSTRACT

The evaluation of driver behavior in dilemma zones is of critical importance to traffic safety and intersection design, but has thus far received limited investigation. Internal and external factors that can influence this behavior include driver demographics, the use of technology in the vehicle, and even the type of dilemma zone—Type I (based on signal timing/intersection geometry) or Type II (based on driver indecision). This paper explores the effect of cell phone technology, calling behavior, and driver characteristics on drivers' decisions to stop or go through an intersection at the onset of a yellow light, along with their corresponding rate of acceleration. A discrete/continuous analysis was adopted that accounted for potential model heterogeneity that may exist across the different dilemma zone types and drivers by applying selectivity-bias corrections. The results suggested that several technology and call behavior combinations are relevant in determining driver behavior, along with gender and age. It was also found that significant differences exist in driver behavior amongst those who decide to stop and those who decide to go through the intersection in a Type II dilemma zone situation. The findings of this paper can support efforts on reducing risky driving behavior in dilemma zones and enforcing distracted driving laws.

1. Introduction

A dilemma zone refers to the region in advance of a signalized intersection where drivers are required to quickly decide whether to stop or proceed when the traffic signal changes from green to yellow. There are two different types of dilemma zones, frequently identified as Types I and II (Hurwitz, 2009), each influenced and controlled by different factors. A Type I dilemma zone, within which drivers cannot adequately clear the intersection during the yellow phase, is associated with physical parameters of the roadway (such as geometric characteristics and speed limit), inadequate length of the yellow phase, and errors in signal timing (Federal Highway Administration, 2008). Stopping behavior within a Type II dilemma zone, also called an "indecision zone", depends primarily on driver characteristics, impairment, and distraction level (Urbanik and Koonce, 2007). This type of dilemma zone is—by definition—more complicated, involving driver behavior that is correspondingly more difficult to understand, explain, and predict.

The literature focusing on Type II dilemma zones and driver behavior can be broadly categorized in two groups: descriptive studies which investigate the correlation of factors such as flashing green, "signal ahead" signs, and driver

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Table 1
Dilemma zone Type II, descriptive studies.

Study	Type of study/data	Measures	Methodology
Gates et al., 2006	• Field study • Video-based data at four high-speed intersections in Madison, Wisconsin; 1,001 observations	Deceleration rates, brake-response time for first-to-stop vehicles, stop-go decisions	• Descriptive analysis • Analysis of Covariance for acceleration rate and brake-response time • Binary logistic regression for stop-go decisions
Gates et al., 2007	• Field study • Video-based data at four high-speed intersections in Madison, Wisconsin; 898 observations	Deceleration rates, brake-response time for first-to-stop vehicles, stop-go decisions, red-light running violation	• Descriptive analysis • Multiple linear regression for acceleration rate and brake-response time • Binary logistic regression for stop-go decisions and red-light running violation
Long et al., 2013	• Field study • Video-based data at four signalized intersections under normal conditions in China; 273 observations • Investigate countdown timer on driving maneuvers after the onset of yellow	Stop-go decisions, correlation between the countdown timer and aggressive acceleration, conservative (abrupt) stopping	• Descriptive analysis • Binary logistic regression for stop-go decisions
Köll et al., 2004	• Field study • Video-based data at ten signalized intersections in Switzerland, Austria, and Germany; 2661 observations • Investigate flashing green before amber effect	Stop-go decisions	• Binary logit model for stop-go decisions
Papaioannou, 2007	• Field study • Video-based data at a signalized intersection in Thessaloniki, Greece; 697 observations	Stop-go decisions, driver classification according to aggressiveness	• Descriptive analysis • Binary logistic regression for stop-go decisions
Elmitiny et al., 2010	• Field study • Video-based data at a high-speed signalized intersection in a typical Central Florida (Orlando) suburban area; 1292 observations	Stop-go decision, red-light running, yellow-entry time	• Classification trees for stop-go decisions, red-light running • Descriptive analysis for yellow-entry time
Yan et al., 2009	• University of Central Florida driving simulator • 42 participants	Deceleration rate, stop-go decisions, red-light running, brake response time	• Descriptive analysis • Logistic regression model for stop-go decisions • Multivariate analysis of variance for brake response time and deceleration rate

characteristics with behavior at signalized intersections (Elmitiny et al., 2009; Gates et al., 2006, 2007; Köll et al., 2004; Long et al., 2013; Papaioannou, 2007; Yan et al., 2009) and predictive studies that attempt to theoretically model the dynamics of dilemma zone and forecast an associated range of driver behaviors (Hurwitz, 2009; Zhixia and Heng, 2013). Table 1 provides a brief description of relevant literature.

As shown in Table 1, past studies have mainly focused on investigating the variations of the main factors associated with drivers' behavior (such as stop-go decisions, acceleration rate, brake response time, etc.). In this pursuit, basic descriptive and probabilistic techniques have been used, such as Chi-square tests, analysis of variance, and multivariate statistics. However, the literature lacks any significant effort to account for the heterogeneity of these factors in influencing the behavior of individual drivers. In contrast, corrective methodologies such as mixed logit models have seen wide application in highway safety research for crash severity analysis (Savolainen et al., 2011), and other safety-related studies (Gkritza and Mannering, 2008; Pai et al., 2009; Pai and Jou, 2014).

In addition, despite the increased amount of dilemma zone related research activity in recent years, there remains a dearth of literature in one key area: distracted driving behavior in dilemma zones. More generally, the literature pertaining