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Examining driver behavior at the onset of yellow in a traffic simulator environment: Comparisons between random parameters and latent class logit models

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ABSTRACT

This study involves an examination of driver behavior at the onset of a yellow signal indication. Behavioral data were obtained from a driving simulator study that was conducted through the National Advanced Driving Simulator (NADS) laboratory at the University of Iowa. These data were drawn from a series of events during which study participants drove through a series of intersections where the traffic signals changed from the green to yellow phase. The resulting dataset provides potential insights into how driver behavior is affected by distracted driving through an experimental design that alternated handheld, headset, and hands-free cell phone use with "normal" baseline driving events. The results of the study show that male drivers ages 18–45 were more likely to stop. Participants were also more likely to stop as they became more familiar with the simulator environment. Cell phone use was found to some influence on driver behavior in this setting, though the effects varied significantly across individuals. The study also demonstrates two methodological approaches for dealing with unobserved heterogeneity across drivers. These include random parameters and latent class logit models, each of which analyze the data as a panel. The results show each method to provide significantly better fit than a pooled, fixed parameter model. Differences in terms of the context of these two approaches are discussed, providing important insights as to the differences between these modeling frameworks.

1. Introduction

Signalized intersections require high levels of driver attention and cognition in order to operate safely and efficiently. Drivers must often make quick decisions, particularly at the onset of the yellow signal phase. Driver errors under such circumstances are a principal factor contributing to intersection-involved crashes and fatalities. In 2012, a total of 4,602 vehicles were involved in fatal crashes at signalized intersections across the United States (NHTSA, 2013), highlighting the need for further efforts to reduce such collisions.

To this end, there has been substantive research into driver behavior at signalized intersections. Much of this research has focused on behavior within dilemma zones or indecision zones, where drivers must quickly determine whether they can safely clear an intersection at the onset of yellow (Köll et al., 2004; Gates et al., 2007; Papaioannou, 2007; Sharma et al., 2007; Elmitiny et al., 2009; Yan et al., 2009; Sharma et al., 2010; Burnett and Sharma, 2011; Zhixia and Heng, 2013; Abbas et al., 2014). These studies have examined how various site (e.g., signal timing, geometry), vehicle (e.g., vehicle type), and driver (e.g., age, gender) characteristics are associated with the decision to stop or proceed through the intersection at the onset of yellow. Deciding to proceed throught the intersection too late increases the risk of angel collisions due to red light running while stopping too soon increases the risk of rear-end collisions. This risk may be exacerbated due to driver distraction, which is becoming an increasing concern due to continuing increases in cell phone use among drivers (Russo et al., 2014).

Increased crash risks due to cell phone use have been a subject of research since 1997, when early work estimated a four-fold increase in crash risk (Redelmeier and Tibshirani, 1997). Subsequent research has shown cell phone use to increase response time and the frequency of traffic violations (Hancock et al., 2003; Patten et al., 2004; Strayer and Drews, 2004; Strayer et al., 2006). Ultimately, the National Highway Traffic Safety Administration (NHTSA) estimates that approximately 400 fatal crashes and 21,000 injury crashes per year involve drivers using a cell phone (NHTSA, 2013). These figures are likely to be conservative given under-

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reporting of distracted driving among police-reported crash data (NHTSA, 2013), further emphasizing the critical nature of this issue.

The extant literature has included three general methods for assessing driver behavior during periods of cell phone use: on-road studies (Young et al., 2013; Klauer et al., 2014); field studies in controlled environments (Hancock et al., 2003; Owens et al., 2011); and driving simulator studies (Strayer et al., 2003; Strayer and Drews, 2004; Beede and Kass, 2006; Strayer et al., 2006; Kass et al., 2007; Strayer and Drews, 2007; Crisler et al., 2008; Charlton, 2009). Several of these studies focused specifically on the effects of cell phone use at signalized intersections (Hancock et al., 2003; Beede and Kass, 2006; Cooper and Strayer, 2008; Horrey et al., 2008; Young et al., 2013).

This study builds upon the existing research literature by assessing driver behavior at the onset of yellow in a traffic simulator environment. The research was conducted as a part of the Transportation Data Competition, which was sponsored by the Transportation Research Board (TRB) Statistical Methods Committee in conjunction with the 2014 TRB Annual Meeting. This competition was aimed at evaluating the appropriateness of various data analytic methodologies for assessing driver behavioral data under such a setting. Several important analytical contributions are provided. First, the results demonstrate significant correlation in the behavior of study participants and unobserved heterogeneity across participants. Failure to account for such concerns may lead to inefficient or biased parameter estimates, providing motivation for two methodological alternatives, which are compared as a part of this study. The results provide insights into those factors affecting driver decisions at the onset of yellow, in addition to highlighting the importance of these methodological considerations.

2. Data and empirical setting

The analysis dataset was made available through the 2014 Transportation Research Board (TRB) Data Competition. This dataset originated from a wireless urban arterial study conducted through the National Advanced Driving Simulator (NADS) at the University of Iowa during the summer of 2004 (Ohlhauser et al., 2011). Simulated drives were performed on the NADS-1, a high-fidelity driving simulator that provided a 360-degree field of view, 13-degree freedom-of-motion, interactive traffic, and actual vehicle cabs. The NADS-1 provides data on vehicle position, velocity, and acceleration at rates of up to 240 Hz.

The participants in this study were required to have a valid driver license and details of the recruitment, screening, and compensation protocol have been detailed elsewhere (Marshall et al., 2010). The intent of the study was to examine the effects of wireless telephone use on driving performance among three age groups. During the study, each participant completed three “drives”. Each drive included three “segments” and each segment involve one rural area and one urban area. Five controlled intersections were encountered during each segment, with two of these intersections involving the onset of a yellow traffic signal indication during the driver’s approach. In total, each driver encountered 18 decision points at yellow onset. Hereafter, each of these decision point sequences is referred to as an event.

During each segment, the participants were randomly assigned one of three cell phone interfaces:

1. Handheld
2. Headset
3. Hands-free

Within each segment, drivers participated in one of three tasks:

1. Baseline —normal driving conditions (i.e., no phone conversation)
2. Outgoing— outgoing call (driver dialing out on phone)
3. Incoming— incoming call (driver answering phone)

The sequences of the baseline events, as well as those involving incoming and outgoing calls, were randomized within each driving segment. All yellow light events occurred while the participant was engaged in the conversation phase of the call. Given these potential sources of driver distraction, the principal focus of this study was to ascertain the effects of wireless telephone use on driver behavior. Specifically, this research examined differences in behavior when drivers encounter a yellow traffic signal indication while approaching a signalized intersection. The initial dataset included information from 1,157 scenarios in which a participant encountered a yellow signal indication while approaching a signalized intersection. These data were drawn from 49 study participants. Training data, which were collected during familiarization runs, were discarded from the analysis dataset. Instances of missing data for relevant variables, as well as cases where values of such variables were infeasible, were also discarded. The final dataset was comprised of 865 runs, details of which are presented in Table 1.

Table 1
Descriptive statistics for analysis dataset.

Variable	Min.	Max.	Mean	Std. Dev.
Young age (18–25 years)	0	1	0.37	0.48
Middle age (30–45 years)	0	1	0.35	0.48
Old age (50–60 years)	0	1	0.28	0.45
Male	0	1	0.53	0.50
Female	0	1	0.47	0.50
Driving event 1	0	1	0.34	0.47
Driving event 2	0	1	0.34	0.47
Driving event 3	0	1	0.33	0.47
Baseline condition	0	1	0.34	0.47
Handheld incoming call	0	1	0.11	0.31
Handheld outgoing call	0	1	0.11	0.32
Headset incoming call	0	1	0.11	0.31
Headset outgoing call	0	1	0.11	0.31
Hands-free incoming call	0	1	0.11	0.32
Hands-free outgoing call	0	1	0.11	0.31
Velocity at onset of yellow (mi/h)	24.6	53.9	42.6	5.0
Distance from stop line at onset of yellow (ft)	109.9	284.7	204.1	33.4
Time to stop line at onset of yellow (s)	2.48	3.81	3.27	0.38
Yellow duration (s)	2.78	4.38	3.84	0.41

The 49 study participants were approximately uniformly distributed among by gender and age group. There were fewer drivers among the oldest age cohort (ages 50–60) and slightly more male drivers than females. Vehicle speeds at the onset of yellow varied from varied from 24.6 to 53.9 mi/h. While speed limit information was not provided as a part of the dataset, the mean speed of 42.6 mi/h suggests a speed limit of approximately 40 mph. The distance of a vehicle at the onset of yellow ranged from 109.0 to 284.7 ft. Considering speed and distance, the expected time to the stop line ranged from 2.48 to 3.81 s. As per the details of the data competition, the duration of the yellow interval was programmed for a constant 4.00 s. However, the dataset showed values ranging from 2.78 to 4.38 s.

3. Statistical methods

A driver decision of whether to stop when encountering a yellow indication at a signalized intersection is a dichotomous (i.e., yes/no) variable. Such data are well suited for analysis by discrete outcome models, such binary logit or probit models. Binary outcome models allow for an examination of the driver behavioral process and how the decision of whether to stop or proceed throught an intersection is related to factors such as driver demographic characteristics,

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